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Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:

https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Reports supporting requests for additional beam time

Reports can be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** **Fast X-ray imaging to study the dynamic response of polymeric foams to laser shock loading**	**Experiment number**: MA-3232
Beamline: ID19	**Date of experiment**: from: December 11, 2016 to: December 14, 2016	**Date of report**: 03-15, 2018
Shifts: 9	**Local contact(s)**: Alexander Rack and Margie Olbinado	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

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Didier **Loison** and Benjamin **Jodar** (IPR, Univ. Rennes)

Séverine **Boyer** (Mines-ParisTech)

Marc **Castaing** and Bastien **Steinhausser** (Thales)

(* all people above are experimentalists)

Report:

Context and background

The aim of the proposal was to study the dynamic compaction of polymeric foams under shock loading produced by laser irradiation in nanosecond regime, using fast X-Ray imaging with ultimate time-resolution (single-bunch imaging). This work was part of an on-going investigation of the response of two polymeric foams to pulsed loads of short duration, including laser driven shocks which allow access to extremely high strain rates (typically 10^7 s^{-1}). Potential applications include the use of such foams to protect structures and equipment against crashes or high velocity collisions. Our background consisted in time-resolved velocity measurements which were used to develop a constitutive model at a macroscopic scale, and post-shot analyses of recovered samples which gave some indirect clues on the compaction processes at a mesoscopic scale, namely pore collapse through buckling and breaking of the polymer matrix. The goal of the ID19 experiment was to use to fast X-ray phase contrast imaging with MHz frame rate to get some direct, *in-situ* picture of these mechanisms, correlate them with the propagation of elastic and compaction waves, and characterize the foam deformation during both loading and unloading.

MA-3232 experiment

After a successful feasibility test [1], a 3 days experiment was performed in December 2016, in collaboration with a German team from HZDR (experiment MI-1266). Participants (see list above) included 4 permanent researchers, 3 PhD students and 3 research engineers. The ID19 staff was deeply involved too, and their efficient help was very much appreciated. Shock loading was generated with a Gaia laser of 5 J-energy and 10 ns-pulse duration kindly provided by Thales. The beam was focused on a 3-4 mm-diameter spot in the surface of a 12 µm-thick aluminum coating through a glass layer or a water drop. Subsequent ablation of a thin absorbing layer produces a plasma. Its expansion toward the laser source drives by reaction a short compressive pulse into the foam sample (about 4×4 mm² with thicknesses ranging from about 1 to 5 mm). Both amplitude and duration of this loading pulse are enhanced by the confining effect of the transparent layer (glass or water).

Single bunch snapshots were recorded with a fast Shimadzu HPV-X2 camera, in 16 bunch mode (8 µm-pixel size, around 30 keV-photon energy, 170 ns-exposure time, short enough to isolate the X-ray flash, about 100 ps-long, from one bunch of electrons in the storage ring).

Results

Unfortunately, a severe breakdown of the Gaia laser following an electrical problem at startup (initially configured for the US voltage !) strongly limited the output energy, below about 2 J first, then less and less until a complete shutdown after a major water leak inside the laser case. Next we switched to a small ESRF laser borrowed from another beamline (which required major revision of the setup). Despite these efforts, the range of loading pressures was barely beyond the elastic limit of the foams (about 30 MPa for the polyurethane foam), so that exploring the compaction regime as initially planned was not possible.

Nevertheless, some sequences showing real-time phase contrast imaging of the propagation of compression waves were successfully recorded (Fig. 1). Mean velocities of the elastic and compaction waves were derived. Furthermore, laser shock-compressed samples were recovered and analyzed using X-ray micro-tomography (Fig. 2). The data were compared to model predictions at both macroscopic and mesoscopic scales.

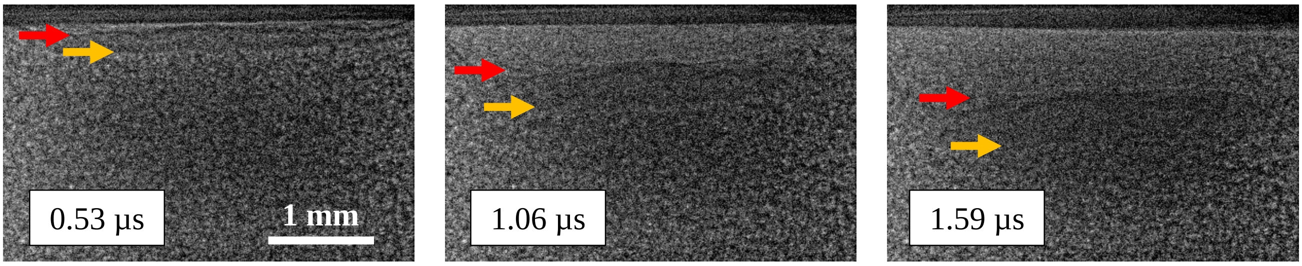

Fig. 1. X-ray phase contrast snapshots of a polyurethane foam at successive times after a laser shock applied on the upper surface, showing the propagation of a compaction wave (red arrows, 0.39 km/s mean velocity), preceded by an elastic precursor (yellow arrows, 0.76 km/s mean velocity) which can be evidenced more clearly by dividing by the static, pre-shock image (see ref. 3 for details).

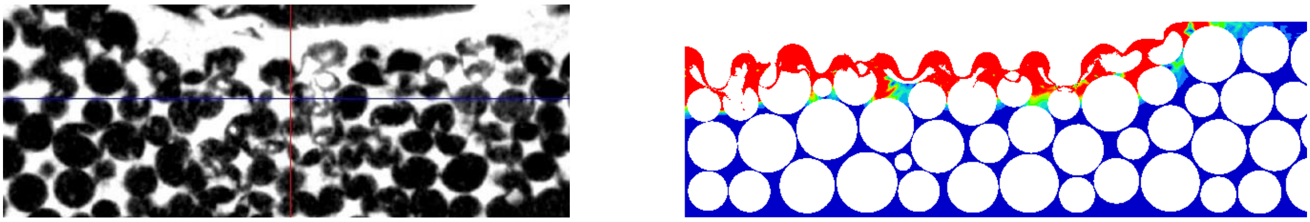

Fig. 2. X-ray micro-tomography of a polyurethane foam recovered after a laser shock applied onto the upper surface, showing pore collapse after buckling and rupture of the polymer matrix (left), and simulation of the foam response to laser shock loading, showing the early stage of wave propagation 0.25 µs after the shot (right).

Further work

Two complementary experiments have already been performed at ID19:

(i) A similar analysis in phase contrast imaging was carried out under quasi-static compression (experiment MA-3755). It allowed improving our interpretation of the images and determining optimum sample-to-camera distances for best phase contrast or best phase retrieval to get a thickness map.

(ii) Two tests were made on the same polyurethane foam under planar impact loading by an aluminum plate accelerated by a gas gun provided by a UK team (Imperial College). The one at higher impact velocity shows very clearly the propagation of the compaction wave front from the impacted surface.

To pursue this effort and reach our initial goal of full characterization of the foams' dynamic response to laser shock loading (high pressures, higher strain rates and shorter load durations than under plate impact), **we have submitted a new proposal on the same subject, based on the use of a TITAN laser** in collaboration with HZDR.

[1] M. Olbinado et al., Ultra high-speed x-ray imaging of laser-driven shock compression using synchrotron light, J. Phys. D: Appl. Phys. **51**, 055601, 2018