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# Equation of state data of plastic foams at Mbar pressures

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Abstract. We present Hugoniot data for plastic foams with normal density in the range 60 - 130 mg/cm$^3$, obtained with laser-driven shocks propagating in Al/foam targets. The experiment was performed using the Prague PALS facility. Pressures as high as 3.6 Mbar (previously unreached for such low density materials) were generated in the foams.

Introduction. Low-density foam layers have the potential of allowing the improvement of target design in ICF [1]; moreover, foams have been used in EOS experiments to increase pressure due to impedance mismatch on foam-solid interface [2]; and finally they are important in astrophysics-dedicated experiments [3]. Therefore, there is a need for increasing the knowledge about these materials, in particular for getting EOS data at strong pressures (Mbar); this is the goal of the experiment presented here. Our method is based on the impedance mismatch technique [4] and the use of Al (in targets) as reference material .

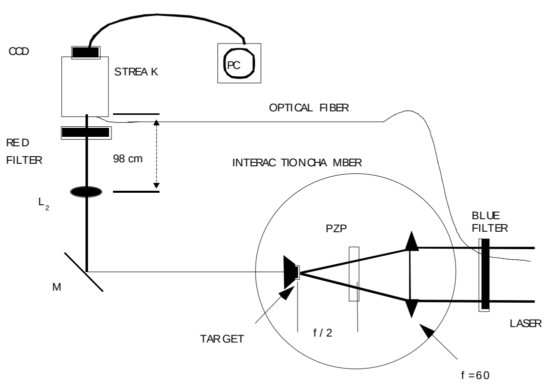


Figure 1: Experimental set-up at PALS.

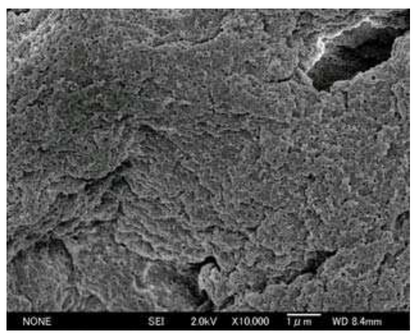


Figure 2: SEM of the foams.

Experimental set up. The experiment was performed with the iodine laser of PALS [5], which delivers a single beam, 29 cm in diameter and 350 ps (FWHM) in duration, with energies up to 250 J per pulse at 0.44 μm (3ω). The diagnostics used to detect the shock breakout from the target rear face consisted in a double lens imaging the rear face onto the slit of a streak camera (Hamamatsu C7700 ). The characteristics of our optical system (PZP + focusing lens) leaded to a focal spot FWHM of 560 μm (400 μm flat region) and to peak intensities up to $2.4 \times 10^{14}$ W/cm$^2$. Our plastic foams ($CH_2$: poly(4-methyl-1-pentene)) were produced at the Target Material Laboratory of ILE, Osaka University, by the aerogel method. The targets had tree layers: a 4 μm plastic (CH) ablator (to reduce preheating), a 10 μm Al foil, a 100-190 μm foam layer coated on half rear face with Al (500 Å).

Experimental results. The streak camera image in fig. 3a shows the breakout from a stepped Al target (base and step were both 5 μm thick).

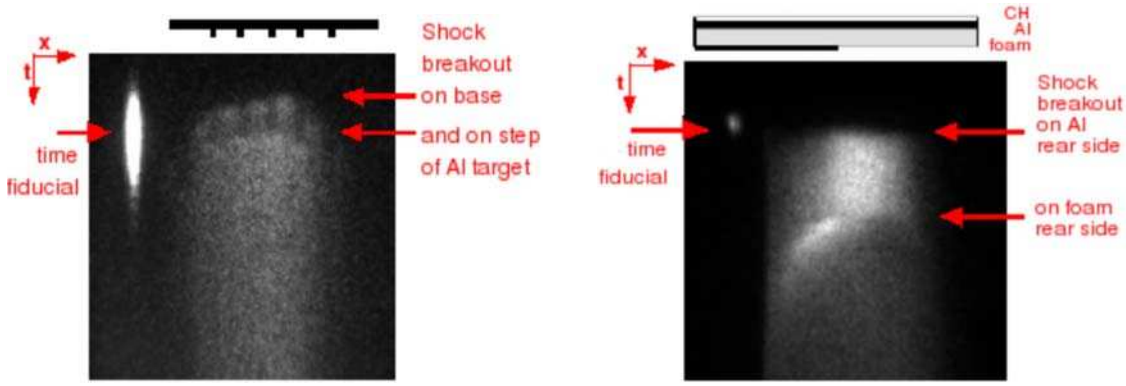


Figure 3: Left) Image (1.60 ns × 1300 μm) of shock breakout from an Al stepped target for laser energy $E_L$ = 229 J. The time delay between base and step is 169 ps giving a shock velocity of 29.6 μm/ns. Right) Image (10 ns × 1300 μm) of shock breakout from an Al/foam target for laser energy $E_L$ = 215 J and foam density $\rho_{\square}$ = 0.055 g/cm$^3$ and thickness 185 μm. The *fiducial to Al-breakout* time is 9 ps, corresponding to a final velocity in Al (last 2 μm) of 33.9 μm/ns. The *Al-breakout to foam-breakout* time is 3088 ps, giving $D_{foam}$=59.9 μm/ns.

The fiducial signal was absolutely synchronized to the laser pulse arrival; so the average shock velocity can be obtained by the *fiducial to break out* time. The experimental velocities (the average one and the final one, which is measured in the step) are both reproduced, within the experimental errors, by the 1D simulations performed using the numerical code MULTI [6], after adjusting the laser intensity. This comparison assures we can infer the stationary shock velocity, via the code simulations, from the measure of the average velocity; and this is the method we use in the case of multilayered targets. Fig. 3b shows a streak image from an Al/foam target (in this case the target front had no CH layer).

When the shock reaches the Al rear side, a strong luminosity is produced and is detected through the transparent foam (but it is partially masked on the left by the Al coating). On the contrary the luminosity due to the shock breakout on the foam rear side is strongly enhanced on the left by the Al thin layer.

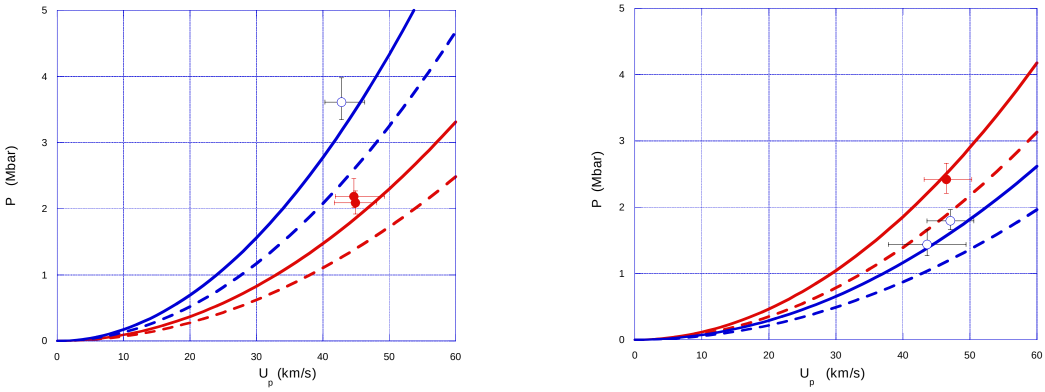


Figure 4: Our results compared to the shock polars (continuous) and the thermodynamical limits (dashed). Left) Results for $\rho_{\square}$ = 0.069 g/cm$^3$ (full circles) and 0.130 g/cm$^3$ (empty). Right) Results for $\rho_{\square}$ = 0.055 g/cm$^3$ (full) and 0.087 g/cm$^3$ (empty ).

Fig. 4 shows our experimental results for 4 different initial foam densities. They are compared to the respective shock polars for a perfect gas, $P = ((\gamma+1)/2)\rho_O U^2$ [7].

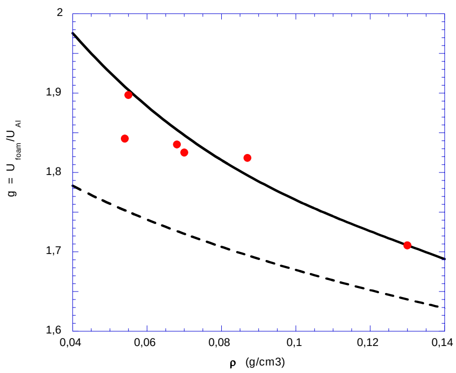


Figure 5: The acceleration factor vs. foam density: our data (circles), “isentropic perfect gas” model (continuous line), “cold material – weak shock” model (dashed).

All results are thermodynamically consistent, i.e. they are above the thermodynamical limits (where D=U or the shocked foam density goes to ∞) corresponding to $P = \rho_O U^2$. From our data it is deducible the acceleration factor ($g = U_{foam}/U_{Al}$) vs. foam density (see fig. 5). We compared our results to two different models. The first calculates the release curve of the Al plasma in the foam as the isentropic in the perfect gas approximation [8].

The second one assumes the Al release curve as the symmetric to the cold Hugoniot. Our results clearly show a much better agreement with the isentropic model, which, in fact, is much more appropriate for the case of stong shocks. The measure of g across a discontinuous density jump may have some relevance for astrophysics (as a limiting case of the shock propagation in the continuously decreasing density profile of a supernova atmosphere).

Conclusions. Pressure as high as 3.6 Mbar were generated in the foams. This kind of foam was not used in the few previous experiments. Samples with four different values of initial density were used. Our P-U points lie close to the perfect gas shock polar. The shock-induced acceleration at the Al/foam interface was measured and it agrees with the Teyssier model [8].

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