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Behavior of Polypropylene Foam under Hydrostatic Loading

D. Kerihuel¹, P. Viot², L. Mahéo^{1,3}, H. Laurent¹

1. Univ Bretagne Sud, IRDL, CNRS UMR 6027, F-56100 Lorient, France
2. Arts et Metiers Paritech, I2M, CNRS UMR 5295, F-33400 Talence, France
3. Military Academy of Saint-Cyr Coetquidan, CReC Saint-Cyr, F-56380 Guer, France

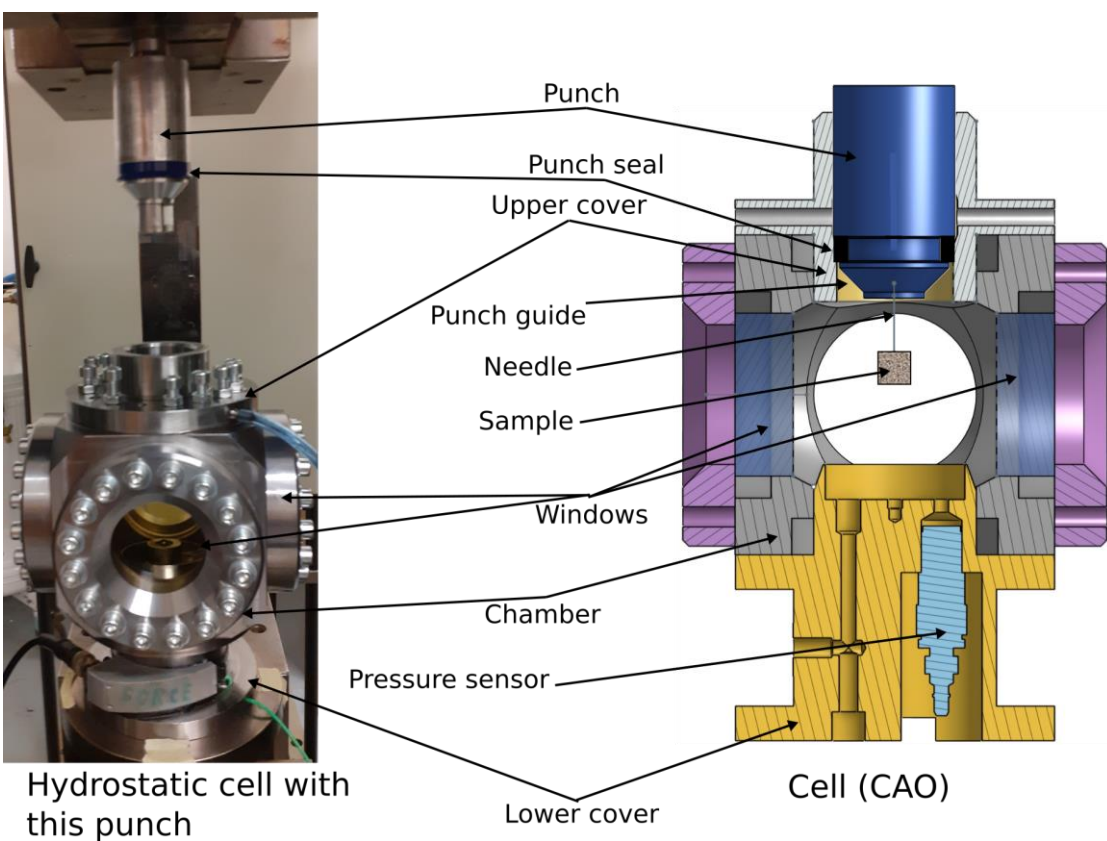
MOTIVATION and REQUIREMENTS

IDENTIFY THE BEHAVIOR OF CELLULAR MATERIAL UNDER THREE-DIMENSIONAL STRESS STATES.

Objectives:

- Develop a new experimental device to measure the pressure vs. volumetric strain.
- Measure precisely the volumetric strain along the test.
- Check the influence of the specimen shape (cylindrical, spherical and hexahedral).

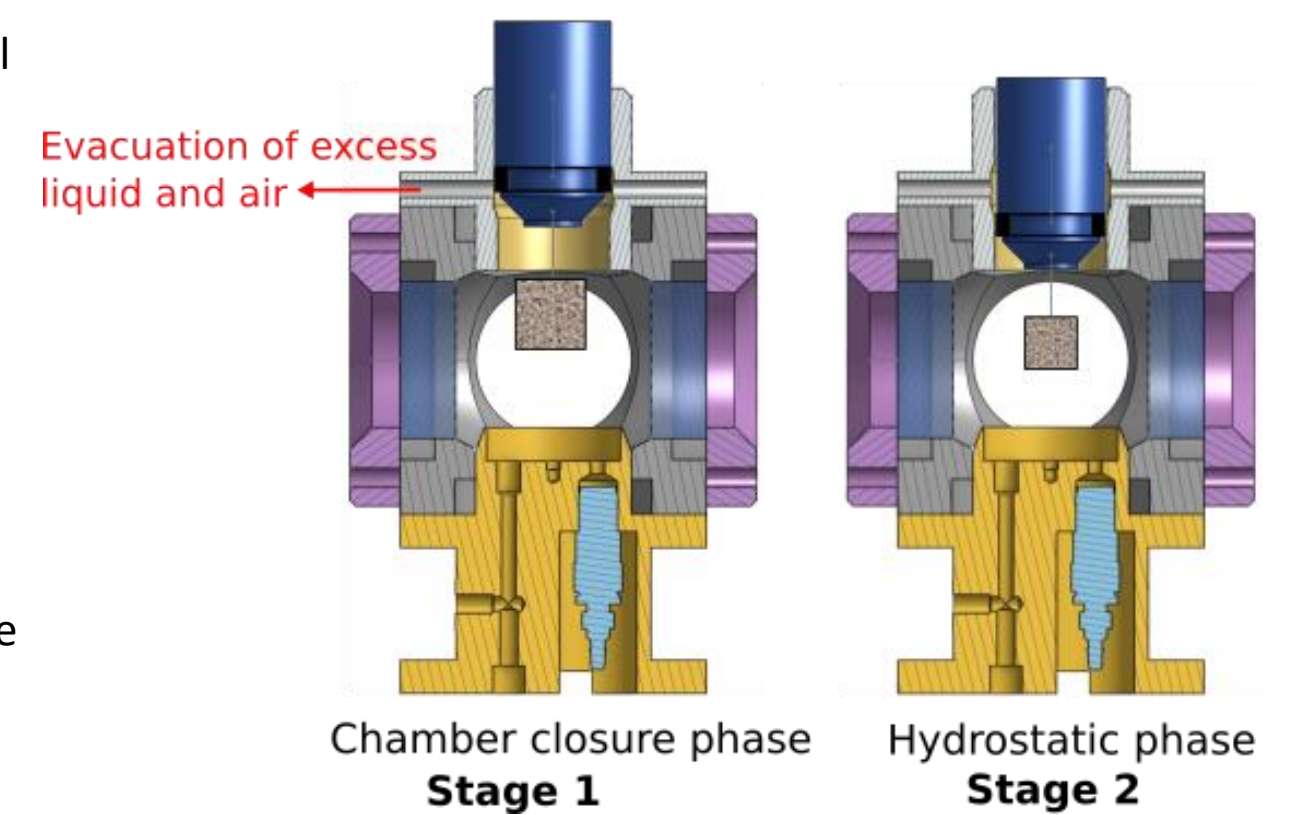
APPARATUS and METHOD



The hydrostatic chamber consists of a metallic box holding a liquid and a steel punch. The sample deformation is visible through three thick glass windows fastened to the box frame. A pressure sensor is fitted to the base of the box.

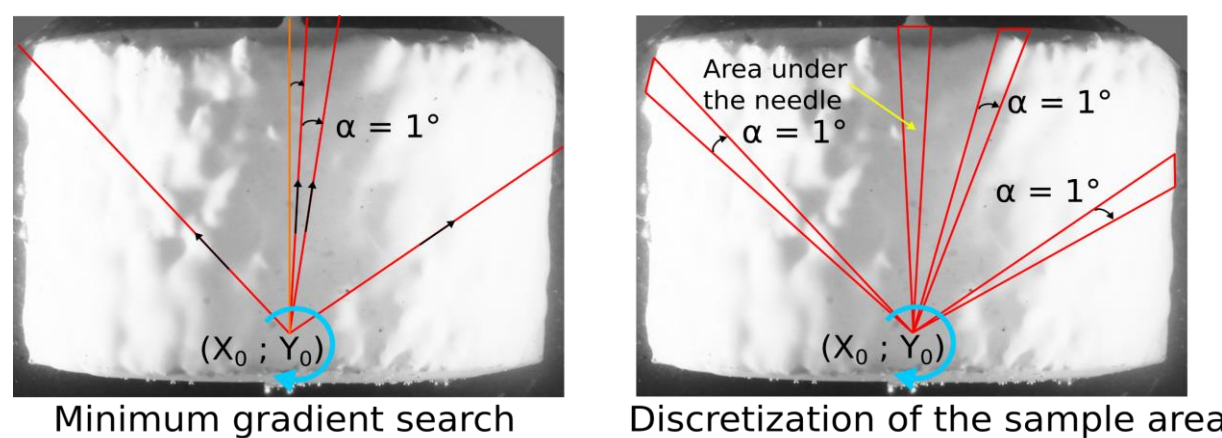
Stage 1 : Before the test, the sample is placed inside the hydrostatic box, mounted on a needle; air bubbles are carefully eliminated since they would significantly the sample volume measurements.

Stage 2 : During hydrostatic compression, the punch displacement causes a volume change in the chamber which deforms the foam. The pressure sensor measures the pressure P (or the hydrostatic stress) in the chamber due to the reaction of the sample.



VOLUMETRIC STRAIN ESTIMATION

From Sample Outline Detection (SOD)



Each hydrostatic compression test was filmed to determine the volumetric strain of the specimen, and to reveal any localization of sample deformation at high volumetric strain.

When the sample was filmed from the side, the projected section of the sample can be determined by detecting its edge.

A routine has been developed to detect the outline of the sample by searching for a grey level gradient over a set of radial segments, it consists of the following steps :

- Definition of the central observation point (same points for all photos).

- Draw a radial segment from this observation point for an angle α_i .
- Detection of a grey level gradient on this segment (grey = sample; black = image background).
- Calculation of the length b_i between the observation point and the gradient point.
- Increment of angle α_i .

• The section can be calculated from the equation :

$$S_{sample} = \sum_{i=1}^n \frac{b_i b_{i+1} \sin \alpha_i}{2}$$

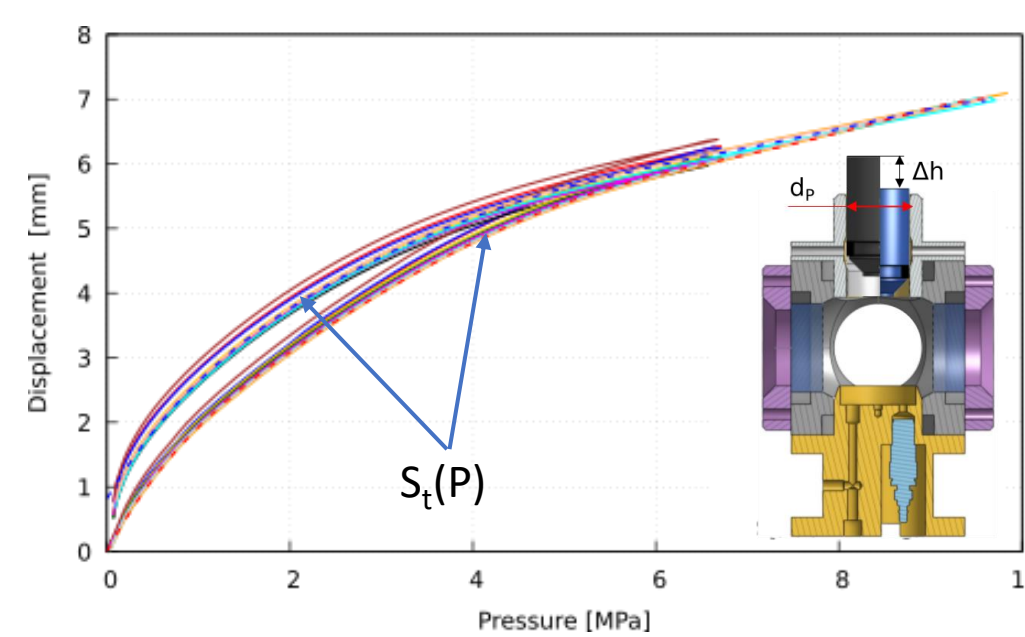
In considering an axisymmetric deformation of the sample, it is possible to determine the volumetric strain from the variation of the section S_{sample} .

$$\text{For a sphere : } V_{shp} = \frac{\pi D_{moy}^3}{6} = \frac{S_{sample} \sqrt{\frac{S_{sample}}{\pi}}}{6}$$

$$\text{For a cylinder : } V_{cyl} = \frac{\pi(h_1 + h_2) D_{moy}^2}{4} = \frac{\pi S_{sample}^2}{4(h_1 + h_2)}$$

$$\text{For a cube : } V_{cube} = c_{moy}^3 = S_{sample} \sqrt{S_{sample}}$$

From Chamber Volume Variation (CVV)



Punch displacement versus Pressure during calibration test (Hydrostatic compression test without sample)

The punch displacement causes a volume change ΔV which is imposed on the foam sample and the chamber.

To take into account the chamber volume changes, calibration tests were performed without sample, measuring the apparent change in chamber volume $S_t(P)$ as a function of the measured pressure P .

This quantity is subtracted from the volume change ΔV (at the same pressure) calculated from the punch displacement, to give the foam volume change.

The volumetric strain $\frac{\Delta V}{V_0}$ of the sample is then calculated from the measurement of the punch displacement $\Delta h(P)$, its diameter d_p , and the cell stiffness $S_t(P)$ and the initial volume V_0 of the sample:

$$\frac{\Delta V}{V_0} = \frac{\pi d_p}{4V_0} (\Delta h(P) - S_t(P))$$

RESULTS

Comparison of strain calculation methods

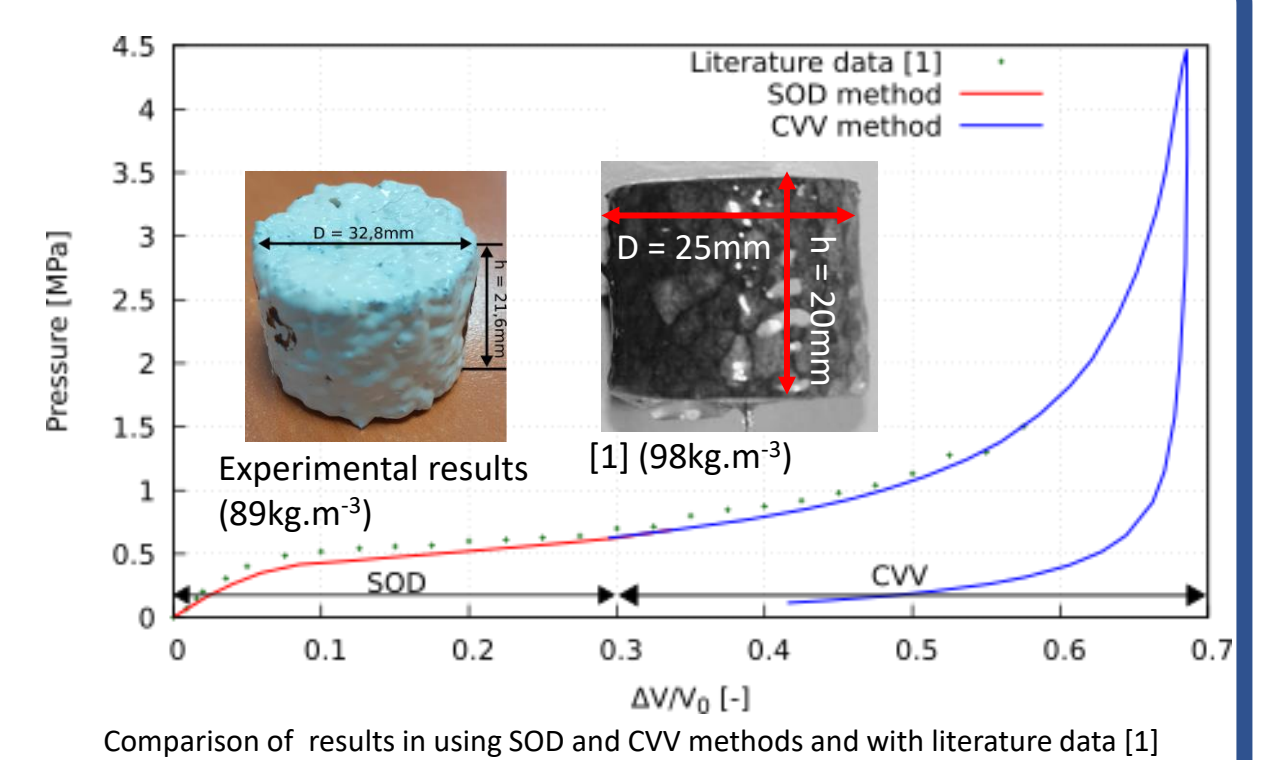
Use of SOD for lower volumetric strain than 30% :

- Chamber stiffness $S_t(p)$ vs pressure P as a function of pressure P is not repeatable; it is due to the deformation of the seals.
- The volumetric strain of sample is axisymmetric.

Use of CVV for higher volumetric strain more than 30% since:

- Chamber stiffness $S_t(p)$ vs pressure P as a function of pressure P is repeatable.
- The volumetric strain of sample is not necessary axisymmetric.

Experimental and literature results are similar.

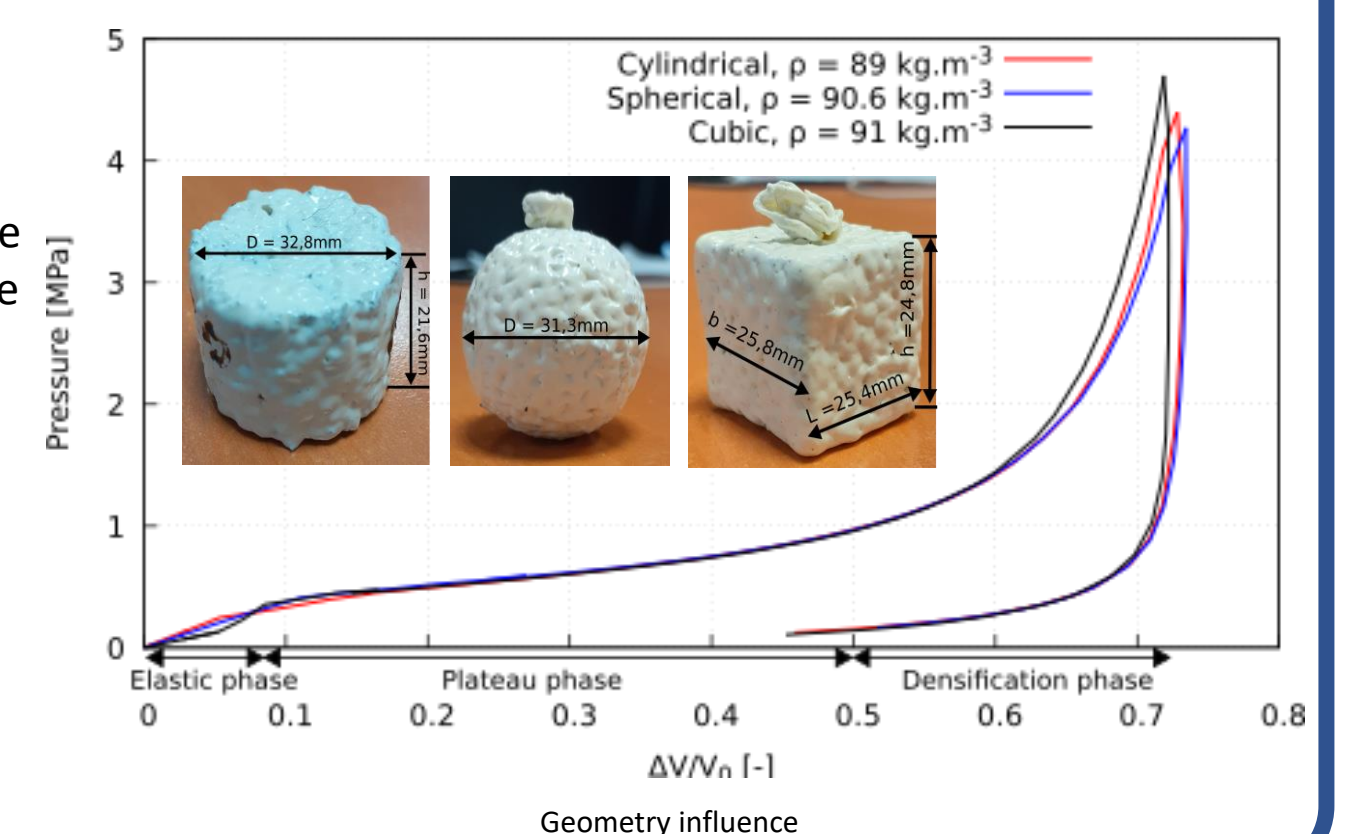


Comparison of results in using SOD and CVV methods and with literature data [1]

Influence of the specimen shape

The response is similar for all three sample shapes:

- During the elastic phase, differences in the measurements are certainly due to the presence of bubbles on the surface of the samples.
- No difference in the pressure vs. volumetric strain response during the plateau phase.
- In the densification phase, for the same variation in volume different changes in shape can be observed for the same variation in volume, depending on the initial shape and the localization of the densification.



References

- [1] Philippe Viot. Hydrostatic compression on polypropylene foam. *International Journal of Impact Engineering*, 36(7):975–989, July 2009.