

TIME TABLE

Registration on Monday at 8.30

TIME	Monday	Tuesday	Wednesday	Thursday	Friday
	July 3	July 4	July 5	July 6	July 7
9.00 - 9.45	Kraynik	Onck	Hilgenfeldt	Hohler	Kyriakides
9.45 - 10.30	Kraynik	Onck	Hohler	Hohler	Hilgenfeldt
11.00 - 11.45	Hilgenfeldt	Kyriakides	Onck	Kyriakides	Hohler
11.45 - 12.30	Hilgenfeldt	Kyriakides	Onck	Kyriakides	Kraynik
14.00 - 14.45	Hohler	Hilgenfeldt	Kyriakides	Gaitanaros	
14.45 - 15.30	Hohler	Hilgenfeldt	Kyriakides	Gaitanaros	
16.00 - 16.45	Kraynik	Hohler	Kraynik	Kraynik	
16.45 - 17.30	Kraynik	Hohler	Kraynik	Kyriakides	

ADMISSION AND ACCOMMODATION

The registration fee is 575.00 Euro + VAT taxes*, where applicable (bank charges are not included). The registration fee includes a complimentary bag, four fixed menu buffet lunches (on Friday upon request), hot beverages, downloadable lecture notes and wi-fi internet access.

Applicants must apply at least one month before the beginning of the course. Application forms should be sent on-line through our web site: <http://www.cism.it>. A message of confirmation will be sent to accepted participants. If you need assistance for registration please contact our secretariat.

Applicants may cancel their course registration and receive a full refund by notifying CISM Secretariat in writing (by email) no later than two weeks prior to the start of the course.

If cancellation occurs less than two weeks prior to the start of the course, a Euro 50.00 handling fee will be charged. Incorrect payments are subject to Euro 50.00 handling fee.

A limited number of participants from universities and research centres who are not supported by their own institutions can be offered board and/or lodging in a reasonably priced hotel or student dormitory, if available.

Requests should be sent to CISM Secretariat by **May 3, 2017** along with the applicant's curriculum and a letter of recommendation by the head of the department or a supervisor confirming that the institute cannot provide funding. Preference will be given to applicants from countries that sponsor CISM.

Information about travel and accommodation is available on our web site, or can be mailed upon request.

* Italian VAT is 22%.

For further information please contact:

CISM
Palazzo del Torso
Piazza Garibaldi 18
33100 Udine (Italy)
tel. +39 0432 248511 (6 lines)
fax +39 0432 248550
e-mail: cism@cism.it

ACADEMIC YEAR 2017
The Kaliszky Session



Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

MECHANICS OF LIQUID AND SOLID FOAMS

Advanced School
coordinated by

Andrew Kraynik
Sandia National Laboratories (retired)
Albuquerque, USA

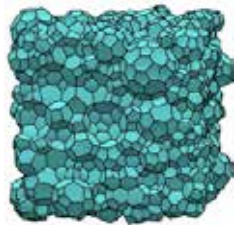
Stelios Kyriakides
University of Texas at Austin, USA

Udine July 3 - 7 2017

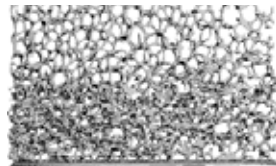
MECHANICS OF LIQUID AND SOLID FOAMS

This course will focus on the relationships between the cellular microstructure and the nonlinear mechanical behavior of liquid and solid foams, as well as foam-like biological and synthetic materials. Consequently, this survey of foam mechanics will explore numerous topics in applied mechanics ranging from traditional fluid mechanics to solid mechanics. Theoretical analysis, numerical simulations, and experiments will be used to unravel the complex relationships between cell-level structure, local deformation mechanisms, and macroscopic mechanical behavior. The cells in liquid foams, such as soap froth, are polyhedral gas bubbles separated by thin liquid films that are stabilized against rupture by surfactants. Many commercially important cellular solids, such as polymer, food, and metal foams, are formed when liquid foams solidify into structures that can have open or closed cells. The growth of spherical gas bubbles in a liquid and their evolution to form the polyhedral cells in low-density foam are key features of foam manufacturing processes, and illustrate the

interplay between the mechanics of liquid and solid foams. The cell-level architecture of low-density foams can be viewed as space-filling polyhedra, forming regular or random networks of surfaces and edges. Similar networks are characteristic of biological materials, such as trabecular bone, the cytoskeleton, and cells in animal tissues such as the eye of the *Drosophila* fruit fly. Liquid foams are used in firefighting, mineral ore separation, drilling fluids and mobility control in the petroleum industry, as well as a wide range of consumer products, foods and beverages. Natural and synthetic cellular solids are lightweight materials with unique and advantageous combinations of properties involving stiffness- and strength-to-weight ratio, energy absorption, thermal insulation and acoustics, all of which can be tuned



by controlling density and cell morphology. Despite significant progress in understanding foam rheology and mechanics over the last few decades, the complex nonlinear phenomena that occur at all length scales remain poorly understood. Whether the structure is two-dimensional and ordered or three-dimensional and highly disordered the fluid mechanics and solid mechanics is very challenging when taking a micromechanical point of view. For solid foams connecting the microstructure and the mechanical properties of the base material to the macroscopic behavior remains a challenge. Models involving idealized ordered microstructures, such as the Kelvin foam, and realistic random microstructures with different cell sizes will be presented, and the strengths and weaknesses in



predicting all aspects of mechanical behavior will be discussed. Taken as a whole, the participants will be presented with the state of the art of the mechanics of liquid and solid foams and will be exposed to many open questions.

The broad course topics are: cell-level foam structure (including a tutorial on Surface Evolver simulations), rheology and aging of liquid foam, and the mechanics of solid foams and biological cellular materials. Both liquid and solid foams exhibit linear elasticity, yielding and plasticity, and the onset and propagation of instabilities.

The target audience for this course includes PhD students and postdocs in engineering, physics, and materials science, as well as young and senior researchers in academia and industry.



PRELIMINARY SUGGESTED READINGS

Gibson, L.J. and Ashby, M.F., 1997, *Cellular Solids: Structure and Properties*, 2nd ed., Cambridge University Press, Cambridge.
Cantat, I. et al., 2013, *Foams: structure and dynamics*, Oxford University Press, Oxford.
Cohen-Addad, S., Höhler, R., Pitois, O., 2013, *Flow in foams and flowing foams*, *Ann. Rev. Fluid Mech.* 45, 241-267.

Gaitanaros, S., Kyriakides, S., Kraynik, A.M., 2012, On the crushing response of random open-cell foams, *Int. J. Solids Structures*, 49, 2733-2743.
Gaitanaros, S., Kyriakides, S., 2014, Dynamic crushing of aluminum foams: Part II – Analysis, *Int. J. Solids Structures*, 51, 1646-661.
Hilgenfeldt, S., Kraynik, A.M., Reinelt, D.A., Sullivan, J. M.,

2004, The structure of foam cells: isotropic Plateau polyhedra, *Europhysics Lett.* 67, 484-490.
Jang, W.-Y., Kraynik, A.M., Kyriakides, S., 2008, On the microstructure of open-cell foams and its effect on elastic properties, *Int. J. Solids Structures*, 45, 1845-1875.
Jang, W.-Y., Kyriakides, S., 2009, On the crushing of aluminum open-

cell foams: Part I experiments, *Int. J. Solids Structures*, 46, 617-634.
Koehler, S.A., Hilgenfeldt, S., Stone, H.A., 2000, A generalized view of foam drainage: experiment and theory, *Langmuir*, 16:15, 6327-6341.
Kraynik, A.M., Reinelt, D.A., van Swol, F., 2003, Structure of random monodisperse foam, *Phys. Rev. E*, 67, 031403.

INVITED LECTURERS

Stavros Gaitanaros - Johns Hopkins University, Baltimore, MD, USA
2 lectures on:
Dynamic crushing and shock development in random open-cell foams; quasi-static vs. dynamic impact; and “subsonic” and “supersonic” behavior.

Sascha Hilgenfeldt - University of Illinois, Urbana-Champaign, IL, USA
6 lectures on:
Foam drainage, rupture and fracture in liquid foams, continuum thermodynamics approach to the mechanics of cellular solids, from foams to tissues: finding mechanical equilibria, Surface Evolver tutorial with student exercises.

Reinhard Höhler - Université Pierre & Marie Curie (Paris 6), France
8 lectures on:
Liquid foam rheology, viscous dissipation, plastic flow, osmotic and capillary pressure, jamming transition, foam mechanics and glassy dynamics, simplified foam mechanics models on the bubble scale, experimental techniques for probing foam structure and rheology, acoustic wave propagation in solid foams.

Andrew Kraynik - Sandia National Laboratories (retired), Albuquerque, NM, USA
8 lectures on:
Overview of foam structure, rheology and mechanics in two and three dimensions, idealized (ordered) and realistic (random) foam structure, foam micromechanics, soap froth rheology, viscous effects, wet foam structure, linear elasticity of solid foams.

Stelios Kyriakides - University of Texas at Austin, TX, USA
8 lectures on:
Experimental, analytical and numerical results on the mechanics of 2D honeycombs and 3D foams (elastic properties, large-deformation compression, instability: onset, localization and spreading, densification, elastic vs. plastic materials), dynamic crushing.

Patrick Onck - University of Groningen, The Netherlands
4 lectures on:
Micromechanics of 2D cellular materials, micromechanics of trabecular bone, fracture of metal foams, mechanics of cross-linked fiber networks.

LECTURES

All lectures will be given in English. Lecture notes can be downloaded from the CISM web site. Instructions will be sent to accepted participants.