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Liquid and solid foams / Mousses liquides et solides

General introduction: Liquid and solid (materials, main properties and applications . . .)

Les mousses liquides et solides : Introduction générale (matériaux, propriétés principales et applications)

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ABSTRACT

A general introduction about the diversity of foam structures is given with focus onto the structural, mechanical and dynamical properties at hand. Two classes of materials are addressed: liquid and semi-solid foams, on the one hand, solid foams, on the other hand. The latter can be subdivided into metallic, ceramic and organic foams, depending on the nature of the solid skeleton that supports the overall cell structure. Solid foams generally stem from the concept of mechanical light-weight structures, but they can just as well be employed for their large surface area as well as for their acoustic and thermal properties. Modern biomaterials use tailored ceramic or organo-ceramic foams as bone scaffolds, whereas hierarchically micro- and nanoporous structures are being used by chemistry to control catalytic reactions. Future materials design and development is going to rely increasingly on natural and synthetic foam structures and properties, be it food, thermal insulators or car frames, thus giving a promising outlook onto the foam research and development that is about to come.

RÉSUMÉ

Cet article constitue une introduction générale à la diversité des structures que peuvent épouser les mousses, avec un coup de projecteur sur les propriétés structurales, mécaniques et dynamiques correspondantes. Deux classes de matériaux sont envisagées : les mousses liquides et semi-solides, d'une part, les mousses solides, d'autre part. Ces dernières se subdivisent en mousses métalliques, céramiques et organiques, selon la nature du squelette solide qui supporte la structure cellulaire globale. Les mousses solides dérivent généralement du concept de structures métalliques légères, mais elles peuvent tout aussi bien être employées pour leur grande surface accessible ou pour leurs propriétés acoustiques et thermiques. Les biomatériaux modernes utilisent des mousses céramiques façonnées ou des mousses organocéramiques comme charpentes osseuses, tandis que des structures hiérarchiquement micro- and nanoporeuses sont utilisées en chimie pour contrôler les réactions catalytiques. La conception de futurs matériaux ainsi que leur développement va de manière croissante reposer sur des structures et des propriétés de

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mousses naturelles et synthétiques, qu'il s'agisse d'aliments, d'isolants thermiques ou de châssis d'automobiles, ce qui nous offre un aperçu prometteur de la recherche dans le domaine des mousses et des développements à venir dans un futur proche.

1. Definition, morphology and properties of foams

Foams can be broadly defined as a sub-category of the so-called cellular materials, i.e. as a two-phase mixture in which gas cells/pores are enclosed into a liquid, semi-solid or solid phase. Cellular materials in turn also comprise the inverse structure, i.e. in which solid or liquid particles are closely packed and surrounded by gas or liquid, as well as liquid–liquid mixtures that are known as emulsions. The structural, dynamic and mechanical properties of foams vary tremendously, whether they are liquid, semi-solid or solid foams, and so does their range of applications. Given the cellular nature of foams, their cell morphology is as important for their properties as are the properties of their individual components. Two types of morphologies are characteristic of foam cells: (1) spherical structures that are simply characterized by (a) the number distribution of radii, and (b) the distance distribution to the nearest neighbors; (2) polyhedral cells that are characterized by (a) faces or lamellas, which are curved thin films separating two neighboring cells, (b) plateau borders, which outline the skeleton of the liquid or solid structure, and (c) junctions of four borders each, the so-called vertices (cf. Fig. 1). In this text, we shall refer to foams as three-dimensional structures, keeping in mind that two-dimensional or quasi two-dimensional (e.g., wood) foams exist as

We encounter foams everywhere in our everyday life: Every plant on this planet is made of solid and/or semi-solid bio-foam, most insects build their hives in cellular arrangements, every car, plane and boat uses solid foams as structural components, every coffee we drink is tipped with a shiny cup of milk micro-foam which provides the unique sensation of fine latte art. Today, we know that even the universe itself has a cellular structure resembling that of foam [1].

2. Overview over liquid, semi-solid and solid foams

Most liquid foams owe their existence to *surfactants*, i.e. surface-active molecules that stabilize the thin intra-cellular films and reduce the surface energy of the phase boundary. In aqueous foams, these *surfactants* are generally hydrophilic on the one end, and hydrophobic on the other end, hence they have a natural tendency to form membranes in water–gas mixtures. Depending on the amount of liquid phase, these foams are referred to as dry foams ($< 5\%$ liquid) or wet foams ($> 5\%$). Fig. 2 shows two transmission radiographs that illustrate the morphological difference between wet and dry foams.

When nanometer-sized solid particles are dispersed in the liquid and then the dispersion is mixed with gas, one speaks of semi-solid foams, the most common example being soap foam, but also many protein foams are being investigated for food applications, in which globular or micellar proteins act as stabilizing colloidal particles (e.g., milk foam); see the articles by Salonen and Fameau, and by C. Monteux, in this dossier. The effect of the particles is to stabilize (over time) the cellular structure by forming a network of semi-solid bridges or clusters inside the cell walls [2], while at the same time slowing down the liquid drainage (more information on dispersions stabilized by solid particles can be found in the article by Schmitt et al., in this dossier). In the case of cream foam, lipid molecules take that role, forming fat globules, which cluster in the cell walls when the air is whipped into the cream. Many metallic foams are being formed in the liquid or semi-solid state; nevertheless we treat them as solid foams referring to their technological use in this state. Polymer foams

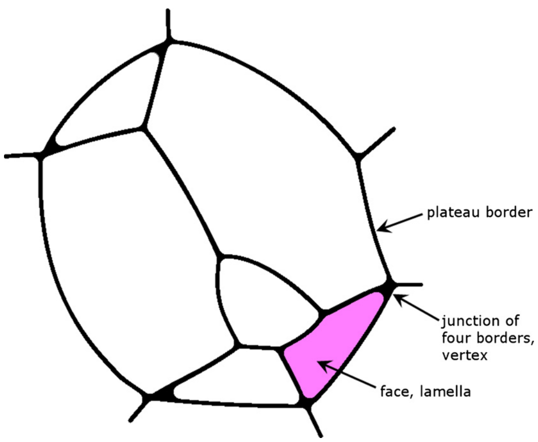

Fig. 1. (Color online.) Schematic drawing of a polyhedral pore in a three-dimensional dry foam.