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Liquid and solid foams / Mousses liquides et solides

Application and future of solid foams

Applications et avenir des mousses solides

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ABSTRACT

To conclude this series of chapters on solid foam materials, a review of industrial current applications and of mid-term market perspectives centred on manmade foams is given, making reference to natural cellular materials. Although the polymeric foam industrial development overwhelms the rest and finds applications on many market segments, more attention will be paid to the emerging market of inorganic—especially metallic—foams (and cellular materials) and their applications, present or upcoming. It is shown that the final applications of solid foams are primarily linked to transport and the present-day development of the different classes of solid foams is contrasted between functional applications and structural applications.

RÉSUMÉ

Pour conclure cette série d'articles sur les mousses solides, celui-ci propose une revue des applications industrielles actuelles et des perspectives de mise sur le marché à moyen terme, centrée sur les mousses artificielles, ceci faisant référence aux matériaux cellulaires naturels. Bien que le développement industriel des mousses polymères surclasse le reste et trouve des applications sur de nombreux segments de marché, on s'attardera davantage sur les marchés émergents des mousses (et matériaux cellulaires) inorganiques – plus particulièrement métalliques – et sur leurs applications, actuelles ou à venir. On montre que les applications finales des mousses solides sont d'abord liées au transport et que le développement de différentes classes de mousses solides auquel on assiste de nos jours est contrasté, entre des applications fonctionnelles et structurales.

1. A short "historical" introduction

Artificial cellular and foam materials were first developed after World War II. Mass production started in the late 1950s with polymeric (mostly polyurethane) foams; however, long before that, in prehistoric ages, man had mastered the attractive attributes of natural cellular materials, like wood and bone, for hunting and building, but also for manufacturing various tools, exploiting their advantageous specific strength (strength/density) or their thermal insulation properties. Some textiles are likely to be the first (semi-)artificial flexible solid cellular materials (not to be further considered). We will include some rigid cellular materials in this presentation. A cellular material may be described as a 2D lattice of tubes, while foam presents a 3D sponge-like structure. As suggested below, the polymeric (and elastomeric) foam development is mature and

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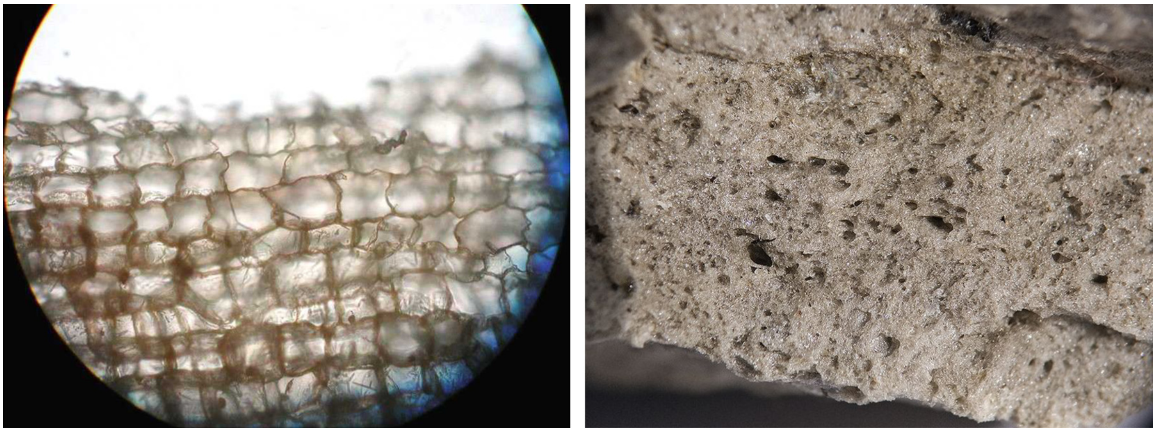

Fig. 1. (Colour online.) Microstructure of natural cellular and foam material. (a) Cork microstructure "à la Hooke". Hooke [2] was the first to identify the cellular structure of cork. From D.B. Fankhauser [4]. (b) Pumice stone with a foam structure. Density may be as low as 0.25 g/cm^3. From Benjamin 444 [5].

will not be developed at great length here, as most of the readers are well informed on if not in daily "contact" with such materials. Metallic foams are still far from maturity and ceramic foams are mature, but have a large potential for further development; we will thus focus on these, referring chiefly to polymeric foams in the context of their use in the fabrication of inorganic foams, some of which are produced starting with polymeric foam prototypes in "replication" processes. We will distinguish solid foams by the material class they belong to, more than by the structure, open or closed cell type. A consideration of the use of natural cellular materials is of interest, since man has a tendency (sound or not?) to mimic nature.

2. Natural cellular materials, applications and market

No natural metallic cellular material is known to the author, although native metals are still to be found on the Earth, of meteoritic origin or of mineral origin, in alluvial deposits for instance (this natural occurrence concerns noble or semi-noble metals plus mercury).

Natural organic cellular materials are extensively used today, and among them wood is prominent, being used extensively for lightweight construction and thermal insulation. Industrial round wood is likely to be, after concrete, the second most widely used material upon the Earth, just ahead of steel [1] with 1.5 billion tons a year, but wood can be both a material and an energy source, which makes statistics difficult to handle. Balsa lumber is a special case since it is light (typically 150–200 kg/m^3) and strong. It is still used in some composite structures and until now in shock-absorbing containers for precious goods.

Cork is a particularly light cellular wood product (which does not require the cutting of the tree to be harvested, since it is positioned in the bark). Natural cork has been studied by materials scientists since Hooke [2]. In spite of its low density, global cork production tops 340,000 tons and 1.5 billion €/year, with wine cork being the most profitable sector, followed by floor and wall covering [3]. It seems that cork oak tree is only grown around the Mediterranean Sea, where it is linked to 30,000 jobs (in the forests and in the transformation of cork). Portugal is by far the biggest producer. Cork, like balsa wood, is a closed-cell cellular material (Fig. 1a). Its useful properties are derived from its closed-cell structure and from a low Poisson ratio, making bottling easier and allowing a good bottle seal. Thermal and sound insulation are appreciated for covering applications in buildings and homes. Synthetic polymeric cellular material substitutes are now available in replacement of wine cork to avoid the rare but unpleasant "corked" taste that can occur in the wine when cork is contaminated. However those materials (solid skin and polymer foam core) ban any exchange between the bottle liquid and the atmosphere, which confers part of its pleasant taste to old wines and the long-term tightness of that recent material is not established yet, which limits their application to cheaper wines today.

Natural cellular ceramic materials are generally of volcanic origin; they include pozzolans, zeolites and tuffs. Pozzolan compositions are based on aluminosilicates, in a vitreous state with bubble gas evolution when the volcanic lava is cooled and solidified. They are advantageously ground and mixed with mortar and lime to produce concrete with lower energy content. Their cellular nature makes them insensitive to freezing/thawing temperature cycles. They tend to be replaced by blast furnace slags, blocky or granulated, i.e. water atomised with a size distribution typical of some natural sands to be incorporated in cement (bringing ∼15 wt% alumina and ∼40 wt% lime in addition to silica). Some of the volcanic minerals may be lighter than water, like pumice stone (Fig. 1b). The extraction of some of these minerals is now banned in a number of countries, since the volcanic areas in which they are extracted have often become natural parks. Owing to their extremely fine structure, zeolites are used for ultrafiltration and as absorption media or catalytic substrates. Coral is also a natural cellular ceramic (with closed cells), but its extraction is forbidden as it is protected nowadays. Trabecular bone is an open cell natural foam material that is not exploited any more as a material.