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Liquid and solid foams / Mousses liquides et solides

Processing and structures of solids foams

Elaboration et structure des mousses solides

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A B S T R A C T

This paper aims at presenting the main processing routes that are used to produce foams in their general definition and the typical structure that can be obtained according to the process. We first describe the main classification of the foam according to the level of porosity (open cells, closed cells, partially open cells and mixed cells). We present briefly the main processes to obtain such structures (non-removable space holder stacking and impregnation, removable space holder, foaming from gas or from precursor and shortly additive manufacturing) with a specific focus on the metal foam processing. We finally indicate the main structure that can be obtained with these types of processes and the main characteristics that are necessary to quantify at the various scale of the structure.

R É S U M É

L'objectif de cet article est de présenter les principales voies de synthèse des mousses dans leur définition générale et la structure typique qui peut être obtenue en fonction de chacune d'entre elles. Nous décrivons d'abord la classification principale de la mousse selon son niveau de porosité (cellules ouvertes, fermées, partiellement ouvertes et mixtes). Nous présentons brièvement les principaux procédés permettant d'obtenir de telles structures (imprégnation ou empilement de particules poreuses, élimination de particules, bullage par injection de gaz ou à partir d'un précurseur et fabrication additive), en mettant plus spécifiquement l'accent sur la réalisation de mousses métalliques. Nous indiquons finalement la structure principale qui peut être obtenue par ces types de procédés et les caractéristiques principales qu'il est nécessaire de quantifier aux différentes échelles de la structure.

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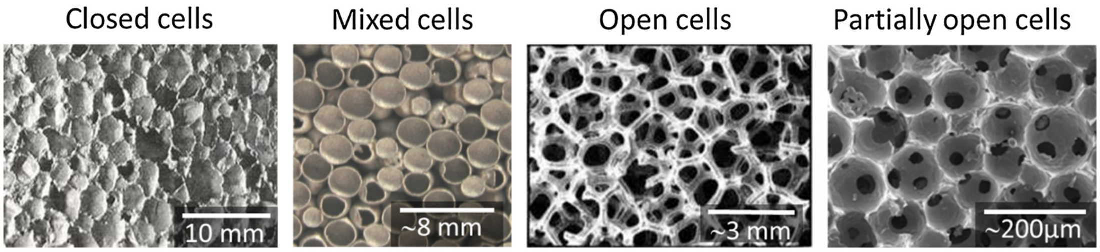

Fig. 1. The different kinds of cellular solids: from closed cells to open cells.

1. Introduction

According to Gibson and Ashby [1], a cellular solid is “one made up of an interconnected network of solid struts or plates which form edges and faces of cells”. There are two types of cellular solids: (i) 2D cellular solids like “honeycombs”, with a geometry that is defined in 2D, (ii) 3D cellular solids, which we will for simplicity call foams, present generally highly porous 3D structures that are divided into distinct cells, a cell being an empty space delimited by solid boundaries. Ideally, the individual cells are all separated from each other by material, but often this restriction is relaxed. In the latter category, one can distinguish between two subgroups: if the material is distributed in the faces and the struts of the cells, the cellular solid is often called closed-cell foams (syntactic foams can be classified in this category). If it is in the struts only (so that the cells connect through open faces), it is called open-cell foams. Intermediate configurations do exist (for example, cell faces are partly solid, or some faces are solid and others are open: in this case, we can use the term “partially open-cell foams”. The last configuration is when the material presents at the same time open porosity and closed porosity like hollow-sphere stacking: we will call them mixed-cell foams. Fig. 1 presents the structure of all these foams. These definitions are valid whatever the constitutive material of the cellular structure: polymer, ceramic or metallic. Note that the term foam should be restricted to cellular materials that are produced by a foaming technique, which is often not the case for open-cell foams, partially open-cell foams and mixed-cell foams, as we will see. However, this term presents the advantage of simplicity and we will keep it to describe 3D cellular structures. The aim of the processing section is to give the general trends, highlighting some specificity according to the constitutive material, rather than presenting an exhaustive review of the processing of all the foams. The structure and the main parameters to characterize cellular solids are quite common to all cellular materials and thus the structural parameters will be presented in reference to foam characteristics (open, closed, partially open and mixed).

2. Processing

Fig. 2 presents the main processing routes that are used to process polymer, ceramic or metal porous materials. This section will be devoted to processes that allow obtaining highly porous materials, i.e. with a relative density larger than 60%. We will briefly present these processes and highlight some features according to the constitutive material: we will consider non-removable space holder stacking, non-removable space holder impregnation, removable space holder, foaming from gas or from precursor and finally additive manufacturing. We will not present in this paper sintered entangled materials.

2.1. Non-removable space holder stacking

The principle is to stack and join hollow particles in order to produce a 3D material. In order to get a structure than can hold, contacts have to be created permanently between the hollow objects. One example of this technique is the hollow metallic sphere stacking process that has been extensively studied over the last ten years [2]. The metallic hollow spheres can be produced from a polystyrene sphere on which metallic particles are deposited using suspension. So far, various materials such as iron, stainless steel, titanium and molybdenum have been used. A de-binding step is required to get rid of polystyrene, followed by a sintering stage to obtain a porous or dense shell. The metallic spheres are stacked (randomly or periodically) and sintered or glued together in order to get a 3D structure. The particularity of this structure is that it is possible to obtain a fully closed cell structure (with a tetrakaidecahedron unit cell) as well as a mixed cell structure with closed porosity (inside the sphere) and open porosity (between the spheres). The size of the spheres is typically a few millimeters, the shell thickness between 50 and 200 µm, and the typical relative density reached is between 0.1 and 0.3. The most developed material with this type of arrangement is stainless steel, but other types of metal can be used [2–4]. Aluminum foam granules [5] that are bonded together can also be used to produce a mixed-cell structure. This process develops under the trade mark APM uses aluminum foam granules of few millimeters in diameter with a relative density between 0.2 and 0.3, which are bonded and mixed, leading to a final product with a relative density as low as 0.1. Recently these granules have been used in polymer matrices as space holders in order to produce aluminum hybrid foam sandwiches as innovative materials for battery housings of electrical vehicles [6].