FreeWIHR: Lattice Boltzmann Methods with Free Surfaces and their Application in Material Technology

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Abstract. Metal foams are interesting as lightweight materials that have an excellent combination of mechanical, thermal, and acoustic properties. However, the production process is currently not fully understood. Therefore, the goal of the FreeWIHR project is the development and high performance implementation of a model for simulating the formation process of metal foams based on the lattice Boltzmann method.

1 Introduction

Foams show very interesting properties with respect to bending stiffness, energy absorption or damping behavior. Nearly every material can be foamed. However, the preparation of metal foams is a comparatively new field of research [1]. An example of an aluminum foam produced via the so-called powder metallurgical route is depicted in Fig. 1. Surprisingly, the physical understanding of foaming processes is yet very poor. This is particularly true for metal foam.

Fig. 1. Evolution of an aluminum foam structure
The main problem associated with the numerical simulation of foaming processes is the huge internal gas-liquid interface which strongly evolves with time. In addition, collapsing cell walls are able to induce avalanche-like coalescence and rearrangement processes of the whole foam structure. The time scale of these highly dynamic processes, which are governed by the Navier–Stokes equations (NSE), is typically much smaller than that of the foam expansion process itself.

A clear advantage of the LB approach compared to CFD lies in its local character, i.e., there are no global systems of equations which have to be solved. The computation time rises linearly with the system size. In addition, boundaries do not have a strong impact on the computation time. These features are essential regarding the complex internal structure of foams [2, 3].

The paper is subdivided into two parts. The first part describes a Lattice Boltzmann Model (LBM) for the simulation of foaming processes. The LBM comprises the underlying physical model and a new algorithm which has to be developed to treat 3D free surface problems within the LB approach. An example demonstrates the potential of the method. The second part describes the implementation and parallelization of the code for the SR8000.

2 Physical Model

The underlying physical model describes foaming by blowing agents including nucleation, bubbles growth, bubble coalescence and eventually foam collapse. The blowing agent releases gas which diffuses to bubble nuclei and leads to foam expansion which is in all stages intimately related with cell coalescence processes. Rupture of the cell walls occurs if their thickness falls below a critical value which is characteristic for the foaming material and is for metals about 20–50 μm.

The foam is considered in the liquid state; i.e., melting and solidification are not taken into account. Due to the large density difference between gas and liquid the two phase hydrodynamic system is reduced to a one phase system which describes fluid flow with free surfaces. That is, the exact dynamics of the gas is not taken into account. At the interface the gas pressure balances the hydrodynamic pressure. Bubble nucleation is assumed to be heterogeneous and statistical. Presently, gas diffusion is simply modeled by a continuous increase of the amount of gas within each bubble which is proportional to the bubble surface.

Pure melts do not foam. Capillary forces due to the surface energy rapidly destroy cell walls by thinning. Prerequisite for the development of a polygonal cell structure is the presence of a stabilizing mechanism. Generally, metal foams get stabilized by particles. The origin of the particles is quite different. They are either deliberately added to the melt or develop during foam preparation. The effect of these particles is to generate a restoring, stabilizing pressure, the disjoining pressure $\Pi$, if they are captured within a cell wall. Both, the effect of the surface tension and the disjoining pressure are treated as a local modification of the gas pressure $p^G$ at the gas-liquid interface $p^G \rightarrow p^G - 2 \kappa \sigma - \Pi$ where $\kappa$ and $\sigma$ denote the curvature and the surface energy, respectively. The disjoining pressure $\Pi$ comprises the forces which stabilize the foam structure. $\Pi$ is a function of the distance to the nearest neighboring interface $d_{int}$

$$\Pi(d_{int}) = \begin{cases} c_H |d_{range} - d_{int}| & \text{for } d_{int} < d_{range} \\ 0 & \text{for } d_{int} \geq d_{range} \end{cases}$$

(1)