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METHODS AND MODELS OF METALLIC FOAM FABRICATION

D. WEAIRE,[1] **S.J. COX**[1] and **J. BANHART**[2]
[1]Department of Pure and Applied Physics, Trinity College, Dublin 2, Ireland
[2]Fraunhofer-Institute for Advanced Materials, Bremen, Germany

1 Formation Process

The new science of metallic foams is growing rapidly, in both the scientific research community and in industrial applications. Several methods now exist for foaming metals. One of these was invented a few years ago at the Fraunhofer-Institute in Bremen [1, 2]. The foam is fabricated from a metal powder, often aluminium, which is mixed with a blowing agent that is chosen to release gas close to the melting point of the metal, e.g. 99.5% aluminium powder and 0.5% titanium hydride powder. This powder mixture is processed to give a dense precursor material which is then heated up to the melting point of the metal. As the metal starts to melt, the blowing agent releases gas and the mixture expands. The resulting foam is then cooled to freeze the structure, resulting in a solid foam. Figure 1 shows an example of such a foam, which can easily be fabricated inside a mould, leading to the possibility of reduced post-processing.

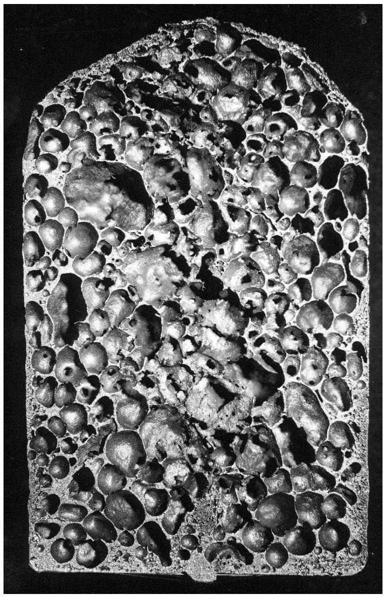

Figure 1: Cross-section through an aluminium foam fabricated by the powder metallurgical process [2]. The foam has been formed in a mould to improve its mechanical properties.

After the expansion phase therefore, the foamed liquid metal undergoes simultaneous liquid drainage and cooling. The liquid drainage, due to gravity, introduces inhomogeneity into the structure, which is generally undesirable in view of the uniform properties required in the solidified structure. If it continues for too long, rupture and collapse of the bubbles will occur. These mechanisms are prevented if the freezing process is rapid enough. Freezing fronts move inwards through the sample, arresting the drainage process. In the model described below we estimate their velocity in relation to the velocity of drainage. Figure 1 shows that uniform foams can currently be fabricated. We wish to define the physical and material parameters which will allow other materials to be foamed with this process.

2 Mathematical Model

We model the process of solidification and drainage, assuming that the bubble melt has been fully expanded. The mathematical representation is based upon the now well-known foam drainage equation, which has been extensively tested and verified for aqueous foams [3, 4, 5, 6]. This nonlinear partial differential equation describes the variation of the liquid fraction of a foam (here we prefer the term *relative density*, since the foam solidifies) with position and time. In the present model this is combined with the equations of heat conduction, so as to describe the motion of the freezing fronts. For more details see [7], which treats a one-dimensional foam, and includes effects such as bubble growth.

These two partial differential equations are nondimensionalised and solved simultaneously, using a finite difference representation. The boundary conditions on the liquid are that there is no flow at the edges of the sample and that the profile of relative density is initially uniform - i.e. the foam has the same wetness throughout. The conditions on the temperature are that it is equal to the melting temperature throughout the bulk and fixed at some applied cooling temperature at the edges.

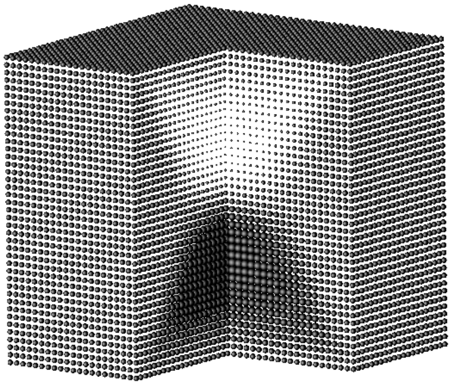

Figure 2: A cube of solidified foam from which a quarter segment has been removed to show the distribution of relative density, which is arbitrarily denoted by the size of the spheres.

3 Numerical Results

Figure 2 shows the distribution of relative density in a cube of metallic foam. Liquid is lost from close to the top, which adds to the relative density in the lower half of the foam. Particular note should be taken of the triangular regions of homogeneous foam. In general, the volume of uniform foam can be increased by changing the aspect ratio of the sample; i.e. by aligning the long side of the foam with the direction of gravity.

4 Theory

A one-dimensional theoretical analysis [7], based upon conservation of liquid and of energy, leads to a prediction of the distribution of relative density in the solidified foam. It shows good agreement with one-dimensional numerical calculations and, moreover, it gives a criterion for obtaining uniform samples of foam. That is, we obtain a relationship between the relevant parameters which describes the conditions under which the degree of inhomogeneity in the finished product will be small. This *homogeneity criterion* is

$$\frac{L_f \rho^2 g L \alpha_0}{\kappa \Theta_{crit} \eta} \ll 1 \tag{1}$$

where L_f, ρ, κ, Θ_{crit} and η are the latent heat of freezing, density, thermal conductivity, melting temperature and viscosity of the liquid metal, L is the length of the foam, Φ_l^0 is the initial relative density, and g is the acceleration due to gravity.

5 Outlook

A great deal of effort is being expended in applying the technology of metallic foams in the automobile industry and elsewhere. Exciting opportunities also exist in the field of microgravity research [8], where the reduced effect of gravity will make these foams easier to fabricate.

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