Development of advanced foams under microgravity

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Abstract

Possibilities for the investigation of novel foam systems under microgravity are discussed. The emphasis is on the investigation of metallic foams which can be made in various ways although the field of interest is much wider and also comprises other aqueous and non-aqueous liquid foams with a high liquid fraction (so-called „wet foams"). A research programme is outlined in which a wide range of liquid foams is investigated under microgravity.

1 Introduction

Exciting new industrial applications of foams have been developed in the past ten years. In particular, metal foams have evolved from a mere curiosity into a range of practical materials which are finding uses in cars and aircrafts. However, this new metal foaming technology still suffers from many deficiencies in comparison with, say, established polymer foam technology. Drainage problems are more serious owing to the high densities and low viscosities of liquid metals. Foam instability also limits reliable and reproducible mass production.

Liquid foams are complex fluids which are particularly poorly understood if the liquid fraction is high. Under normal conditions the inevitable presence of gravitationally driven drainage makes an investigation of coarsening, of the influence of surface active elements and of viscosity-enhancing additives very difficult, because of the rapid variations of foam properties induced by the gravitational flow. One would like to remove these limitations in order to generate improved models of the foaming of materials, especially metals. Microgravity could serve as a valuable tool to isolate some of the key factors which influence foam stability, namely surface tension and viscosity. Moreover, a unified approach in which foams of various materials, ranging from water and non-aqueous organic liquids to various metals, are investigated in a consistent manner would be desirable to create cross-fertilisation of currently unrelated research areas.

In the past 40 years many attempts have been undertaken to foam metals but the methods developed suffered from relatively high costs and a poor quality of the foamed material. In the last ten years, however, there have been quite some improvements, so that nowadays various methods for making metallic foams are available. Some start from the molten metal, others from metal powders [1]. In particular, a powder method for foaming metals was invented a few years ago at the Fraunhofer-Institute in Bremen. It allows for foaming many metals and alloys based on, e.g. aluminium, zinc, tin, lead, or gold. Foamed metal can be produced by the following recipe:

1. A metal powder is mixed with a blowing agent, e.g. one mixes 99.5% aluminium powder and 0.5% titanium hydride powder.

D. Weaire and J. Banhart: *Foams and Films*, © MIT Verlag Bremen (1999)

2. The powder mixture is hot pressed yielding an almost perfectly dense precursor material.
3. The precursor is heated up to the melting point of the metal. As the metal starts to melt the blowing agent releases gas - hydrogen in the example mentioned above. The melting body starts to expand slowly and increases its volume. Because the process takes place in the liquid state, the pores and the outer surface are closed owing to the effect of surface tension.
4. Lowering the temperature the foam structure can be frozen resulting in a solid metallic foam.

Figure 1 shows various stages of the evolution of a zinc foam. One sees the continuous growth of the bubbles but also the effect of drainage creating denser sections on the bottom part of the foam.

Figure 1: various stages of the evolution of a zinc foam (scale 3:1)

Alternatively, metallic foam can be created from the liquid metal directly in complete analogy to the creation of ordinary soap froth. The corresponding steps are:

1. A foamable metallic liquid is prepared. This requires the addition of some other metals or inorganic compounds in order to adjust the viscosity of the melt.
2. A blowing agent is added to the bath of molten metal. For aluminium melts the blowing agent usually is a powdered metal hydride which releases hydrogen when it comes into contact with the molten metal. If a sufficient amount of hydride is added, the entire metal pool starts to bubble and slowly expands.
3. The expanded metallic foam is cooled below the melting temperature of the metal and a solid foam is created this way.

Step 2 can be varied:

2a. Instead of using a blowing agent, gas is injected into the melt directly. For this rotating impellers or vibrating nozzles are used. They create a multitude of fine bubbles which slowly rise to the top of the liquid where the resulting foam accumulates.

For aluminium the viscosity of the melt can be enhanced by adding calcium metal [2] (causing the formation of calcium-aluminium oxides by reacting with the oxygen always present in technical aluminium melts) or by adding up to 15% of fine silicon carbide particles [3].

All described methods for making metallic foams are being exploited by companies trying to establish themselves on the emerging market for such materials. In particular there is the German „Schunk Sintermetalltechnik" and the Austrian „Neuman AluFoam" working on the powder route and the Norwegian „Hydro Aluminium", the Canadian „Cymat" and the Japanese „Shinko Wire" following the melt route.

2 Deficiencies

Although metallic (and here mostly aluminium) foams are becoming more popular there are still some problems which have to be solved to satisfy the industrial demands:

- some foam properties have to be further improved for commercial applications
- occasionally there are stability problems (collapse of foam) especially when making complex parts
- the conditions which lead to good foaming properties are not sufficiently well known
- new knowledge is often obtained in an empirical way instead of being based on a profound theoretical knowledge

3 Microgravity approach

The foaming of metals is far less investigated than the foaming of other, more conventional materials and shall therefore be the main point of interest in the future programme. Figure 2 shows the various ways how metal foams (mostly aluminium) have been investigated in the past and present and how they might be investigated in the future.

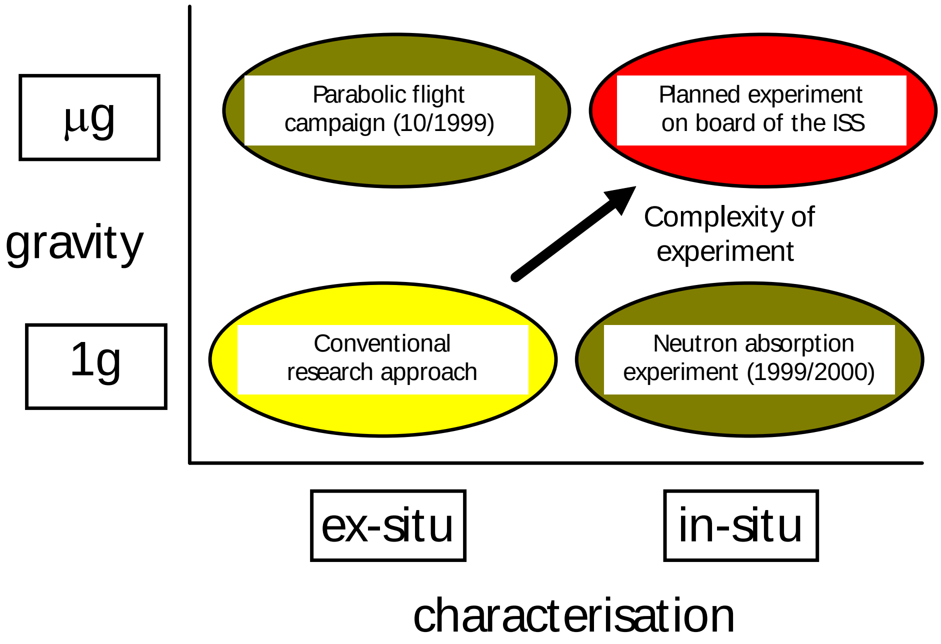

Figure 2: research approaches to the characterisation of the foaming behaviour of metals

The <u>conventional</u> method for characterising solid foams is to produce them under terrestrial conditions (1g), to vary process parameters and to characterise them **„ex-situ“** after solidification. This method helped to develop most of the current knowledge about how to foam metals but clearly does not help gaining very much insight into the physics behind foaming.

A research programme which has now started [4] includes **„in-situ“** characterisations of the evolving metal foam with an apparatus measuring the volume expansion with time and an experiment characterising time-dependent density variations by neutron absorption.

A current research programme [5] includes the production of lead foams in parabolic flights to explore the basic phenomena occurring under microgravity. The investigations are „ex-situ“, i.e. the samples produced under microgravity are analysed after the flight campaign.

An important innovation would be carrying out **„in-situ“** experiments under **microgravity,** i.e. observing a metallic foam evolving under microgravity. Parabolic flights cannot be sufficient for this purpose since the available time in such experiments is too short. Therefore, this experiment is clearly a candidate for the future utilisation of the International Space Station (ISS).

The strategy is to utilise microgravity as a tool in order to elucidate mechanisms of foaming and foam evolution of various aqueous, non-aqueous and metallic systems. The research programme plans to set up a facility operating on the ISS which possesses a new and unprecedented combination of bubble and foam preparation and characterisation tools. The main characteristics of the facility are:

- the facility is modularised containing a furnace, a foaming tube, field and current generation unit and the foam diagnostics module. The modules are exchangeable.
- the range of materials to be foamed will be very wide to be able to gain access to as much data as possible
- variable atmospheric conditions can be chosen (vacuum, oxygen,...)
- possible diagnostic tools range from optical observation (video), light scattering, resistance measurement to inductance measurements and ultrasound probing. Building up the latter is a major challenge, because there is not much experience with such measurements.

The plan at the moment is to be able to implement the 6 different types of experiment (E1-E6) schematically described in Figure 3.

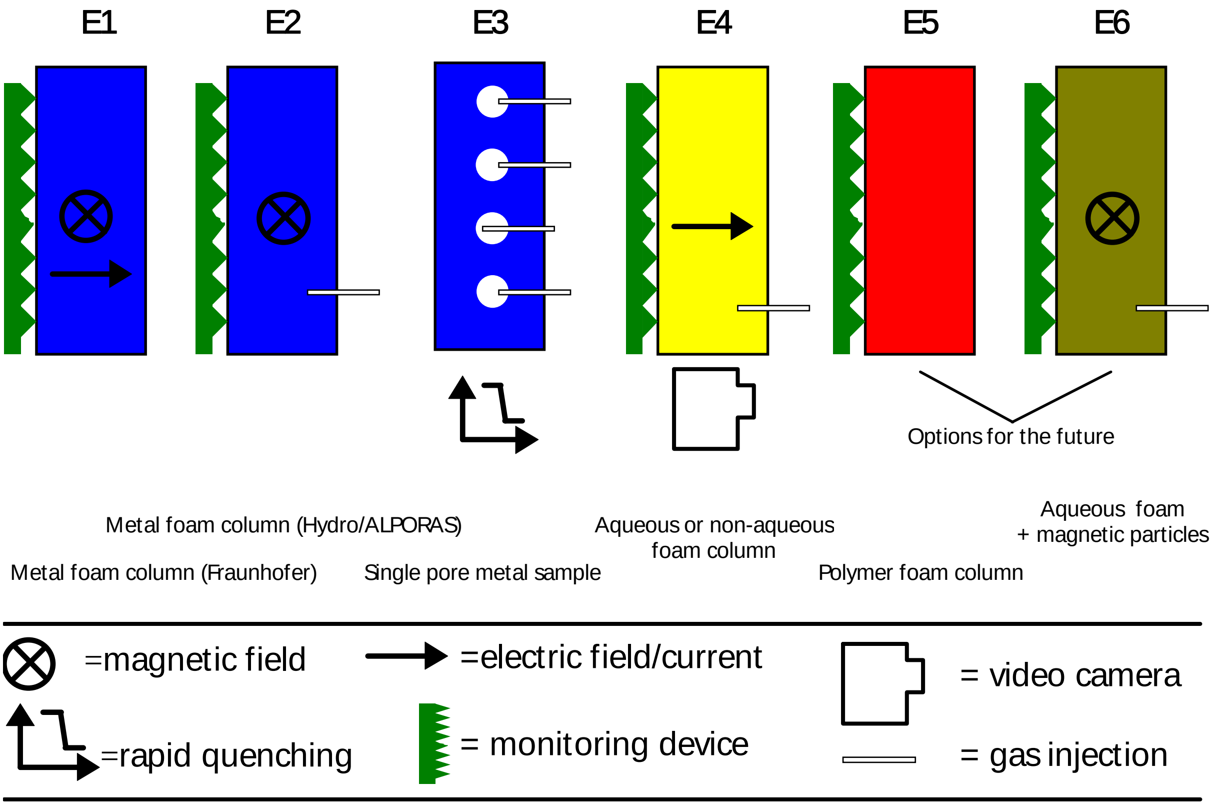

Figure 3: schematical description of the six planned experiments

E1: A metallic foam column is produced following the powder-metallurgical Fraunhofer-process. The evolution of the foam is monitored by means of a ultrasound or inductance device. Magnetic fields (up to 1.5 Tesla) can be applied to damp convective flows in the foam or to create a force in conjunction with an electric current (densities up to 3A/cm^2). The second option allows to drag the bubbles to one or the other side of the foam and this way to densify or to deform the foam and to observe effects of viscosity directly. Mostly zinc and aluminium alloys will be investigated.

E2: A metallic foam is produced by injecting gas or adding a blowing agent to a special melt to which viscosity enhancing substances have been added (Hydro Aluminium or Alporas process). The measurements on such foams are analogous to the ones in E1.

E3: The container now contains a very clean metallic alloy melt into which gas bubbles (O_2, Ar) are injected at various locations. From our current knowledge it is predicted that two processes will occur which are important for foaming: there will be chemical reaction between the gas O_2 and the metal and there will be a diffusion of some of the alloying elements dissolved in the melt towards the fresh metal/gas interface. The sample is directionally solidified creating a chain of bubbles representing different stages of diffusion. The inner walls of bubbles inflated with oxygen will contain a layer of oxide which is believed to lower surface tension. The samples are analysed after flight (ex-situ) with respect to bubble size and shape, chemical composition of the interface zone between bubbles and metal (thus measuring the diffusion time scale) and thickness of the surface oxide layer.

E4: An aqueous or non-aqueous foam is generated by injecting gas into a liquid through glass capillaries. The process is monitored by video. The type of surfactant is varied to explore the role of surface elasticity. The gas flow rate and the size of the capillaries are also varied to explore the role of bubble size. Electrical fields are applied to study the motion of isolated bubbles (for foams with a high liquid fraction). This will allow the determination of the surface electric potential of the bubbles which is suspected to be also an important parameter for foam stability, but which is impossible to measure on earth (due to the buoyancy force).

E5: A polymer foam is created and analysed during and after foaming.

E6: An aqueous foam with suspended ultra-fine magnetic particles is created. The liquid can be influenced by a strong applied magnetic field.

4 Objectives

The main objective of the proposed programme is to gain insight into the evolution behaviour of wet foams (aqueous, non-aqueous, polymer, metallic) in order to solve problems associated with the commercial production of such foams. By investigating at least two different kinds of foams (aqueous and metallic) a unified view of the problems and phenomena encountered can be obtained. Figure 4 shows the main goals of the proposed programme in graphical form ordered from top to bottom according to a classification as scientific or very application-oriented objectives.

The scientific problems to be solved are related to basic questions of the existence and evolution of foams. Mechanisms of pore inflation, coalescence and material flow (under microgravity and driven e.g. by surface tension and Marangoni convection) are to be investigated without the presence of disturbing gravitational flow effects.

All scientific results will be reviewed at an early stage whether they allow for improvements of the currently very dynamic evolution of industrial production technology. It is a goal to create spin-offs already in the preparation phase of the actual ISS experiment and of course during and after the ISS campaign which allow improvements of foaming, especially for metals. Another objective is to explore a regime in which "new types of solid foam" can be formed which could be possible because in microgravity drainage ceases to be an important (and restrictive) factor in foam evolution and formation.

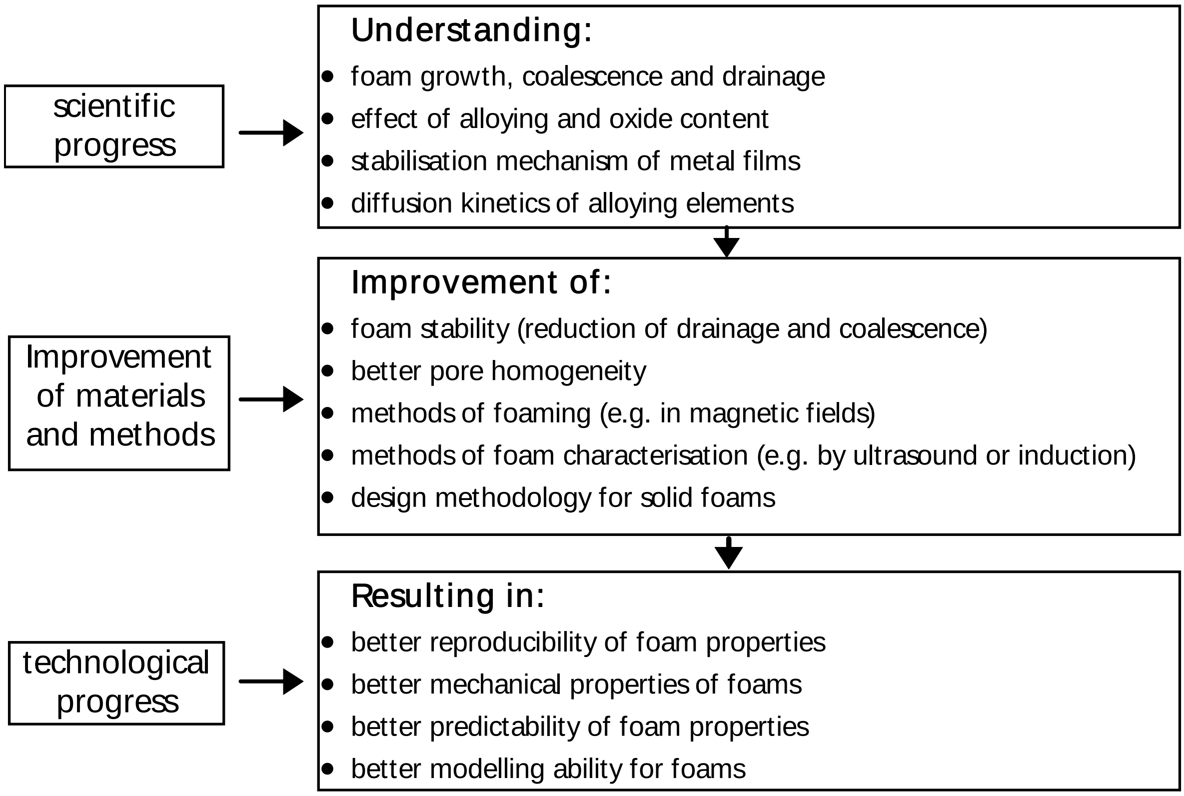

Figure 4: Objectives of a microgravity research programme on foam

5 Summary

Microgravity is a valuable tool in solving problems associated with the development of novel foams such as the rather new metallic foams. Because disturbing effects of drainage can be eliminated, an examination of other effects during foaming, e.g. driven by surface tension or by external magnetic and electrical fields, is facilitated.

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