Fast radioscopy on liquid metal foams

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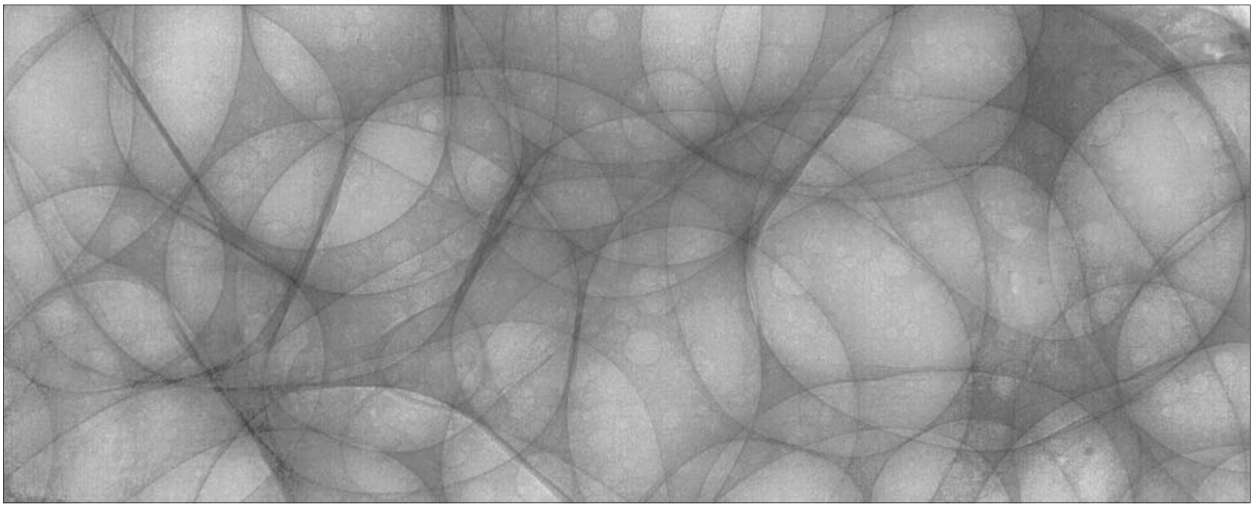

Fig. 1: X-ray radiograph of an evolving metallic foam taken with an exposure time of 600 μs

Radiography with penetrating rays can help to visualize the structure of opaque materials (Fig. 1). To study time dependent phenomena we need a series of radiographies, known as radioscopy. X-ray tubes can be used to study these phenomena, e.g., to visualize oxide films during solidification of aluminium alloys, growth of hydrogen pores in aluminium castings, or convective flow in liquid metals. However, the flux of conventional x-ray sources limits both the accessible frame rates to a few frames per second and spatial resolutions to some 10 μm. Thus in order to study processes in higher spatial and temporal resolution synchrotron radiation is applied.

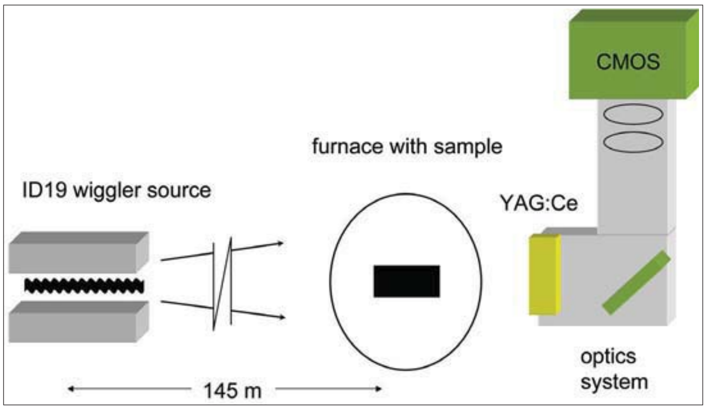

Fig. 2: Sketch of the fast imaging setup used on the ESRF's ID19 beamline

X-ray radioscopy, and especially synchrotron radioscopy, has gained considerable importance for the in-situ examination of evolving metallic foams within the last decade [1]. A common phenomenon in metal foams is coalescence. Thermal or mechanical instabilities lead to the rupture of a film separating two adjacent bubbles and their subsequent merger. It is important to understand the dynamics of these rupture events because they reflect the properties of the constitutive liquid. It has been estimated that these ruptures take place on a time scale of a few milliseconds or even faster. To image them, a very high frame rate is required.

We conducted an investigation of liquid metallic foams by means of high-speed radioscopy and captured 5000 images/s to reveal the details of pore coalescence during growth of Al-6%Si-4%Cu (wt. %) alloy foam [2]. Imaging experiments were carried out using the ID19 beamline at the European Synchrotron Radiation Facility, ESRF. A quasi-white spectrum of ID19's wiggler (gap 40 mm) was used in order to achieve the flux of $\approx 10^{15}$ photons/mm^{2}s required for our fast imaging application. The beam was filtered by 1.5 mm of aluminium (including the two pressure vessel walls). We chose a PCO (10-bit dynamic range, 60 dB, 12 µm pixel size) as the fast camera. In order to reach the required 5000 frames/ s (200 ms exposure time), we restricted the region of interest to 1280×128 pixels. Fig. 2 shows a sketch of the setup.

The metal foam furnace setup utilised for the experiments consists of a ceramic heating plate placed inside an Al-cylinder (wall thickness: 0.5mm). This cylinder is closed tightly at both ends allowing vacuum and overpressures of up to 10 bar, with connections for heating current, thermocouple and gas in- and outlet. The system is described by the authors in detail in the literature [3].

The furnace was loaded for the experiments with a foamable Al-6%Si-4%Cu + 0.5 wt.% TiH_2 precursor measuring 10 x 5 x 4 mm^3, closed and placed in the beam path. Then it was filled with Ar up to 5 bar and the sample heated up at 25-30 K/s to T = 600°C. After melting, the gas contained in the blowing agent nucleates in the sample leading to a small expansion of ~ 5 – 10%. The pressure in the furnace is then decreased to normal by releasing the gas, a process called Pressure Induced Foaming (PIF) [4] which takes about 5 seconds. During this time, the camera records the foam evolution. The quick expansion produced by the pressure release accelerates the kinetics of foaming, leading to an increased occurrence of cell wall ruptures. The reason for using this method is to increase the number of ruptures during foaming to several hundred (by comparison with around 0-5 ruptures/s in standard foaming) in order to gather enough statistics during the limited measurement time of a few seconds.

In Fig. 3 we can observe the rupture procedure of a cell wall in an Al-6%Si-4%Cu foam in detail. The pore diameters of the foam are in the range of ca. 1-5 mm. The time interval between 2 consecutive images is 200 µs, leading to the total rupture and formation of a new cell wall in t_r = 600±100 µs. The diameter of the bubbles in question is in the range of 3 mm.

Of course, radioscopy does not reveal the true position of all the material and, therefore, we cannot specify how the rupture event was initiated and where exactly the metal in the ruptured features has been redistributed. But by a simple calculation we can affirm that during rupture, viscosity plays a minor role compared to liquid film inertia [2]. In this case, the liquid movement is largely dominated by inertia. This shows that the time taken for individual films to break suggests that the effective viscosity is that of the pure liquid within one order of magnitude.

In the literature, it has been proposed that a foam-stabilizing mechanism may be achieved via dramatically enhanced viscosity which is caused by the formation of a filigree network of oxides forming a gel. It has been found that an apparent viscosity of 400 mPas is the reason for the observed stability of foam columns. With such a high value for viscosity, viscous damping would lead to measurably higher values for t_r. A network of oxide fragments, clearly discernible in microscopic images of solidified foams, might give rise to high viscosity in an undistorted state and block liquid flow out of the films. After rupture, however, this network seems to have broken up. The viscosity of the liquid in the film appears to depend strongly on the history of the melt and the forces acting on it.

In conclusion, using white synchrotron x-ray radiation, a suitable fluorescent screen, and a fast CMOS camera, x-ray image sequences comprising up to 5000 frames/s can be acquired. The temporal evolution of the rupture of an individual metal film within a metallic foam was observed. The observed rupture time of about 600±100 µs is in agreement with a simple model that assumes inertia-limited film rupture and expresses the fact that the liquid in rupturing films is very fluid and behaves like a conventional melt.

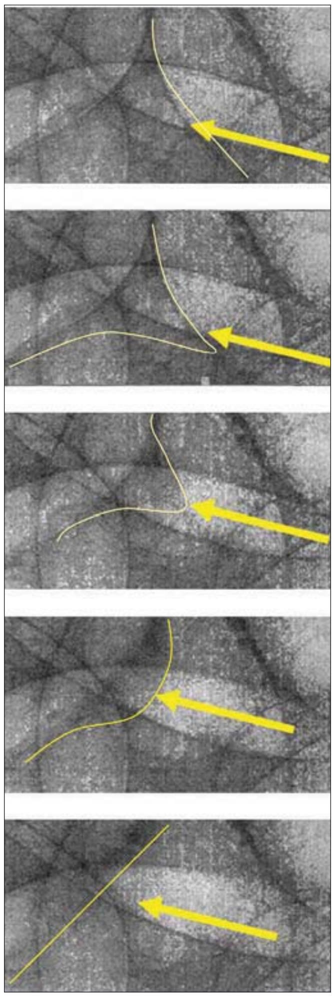

Fig. 3: Radiographs of a metal foam featuring a rupturing film. Images are 200 µs apart. The yellow line denotes the position of the rupturing film.

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