ESRF	**Experiment title:** Investigation of foaming process and material distribution in metal foams.	**Experiment number:** ME-212
Beamline: ID19	**Date of experiment:** from: 27/05/01, 07/11/01 to: 01/06/01, 10/11/01	**Date of report:** 01/03/03
Shifts: 12+9	**Local contact(s):** L. Helfen	*Received at ESRF:*

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Report:

In the scope of experiment ME-41 we investigated foam formation *in situ* by integration of a dedicated furnace into the beam path of ID19. Results from this experiment were published [BSHB01, BSH+01]. The same set-up was applied in the experiment ME-212 in order to investigate technologically relevant issues like the foam flow behaviour or the effects of defects deliberately included into the foamable precursor material [Ban01]. Moreover, the abilities of the ESRF Frelon CCD camera for achieving high frame rates were tested. Results are published in [SWW+02, HSO+03].

The defect investigations were carried out on a variety of precursor materials and defect types [SWW+02]. The aim was to evaluate in how far the defects affect the foam structure in their surroundings.

We show in this report the example of an M2 steel washer of mass M =32.4 mg compacted into the AlSi7 (7 wt-% silicon) precursor material. The precursor material was introduced within a foaming mould (made from titanium) into the pre-heated furnace. It was observed that the foam structure is not significantly different from a foam structure without any defect. From Fig. 1 we see that the foam supports the washer by the formation of a supporting structure of Plateau borders around it. Even after around 9 minutes of foaming the foam structure exhibits no significant collapse. Other deliberately created defects lead to local pore formation of big voids especially if defects are non-metallic. These voids, however, did not lead to the expected pores in the fully expanded foams. A slight density increase around the defect seems to be the main consequence in most cases [SWW+02].

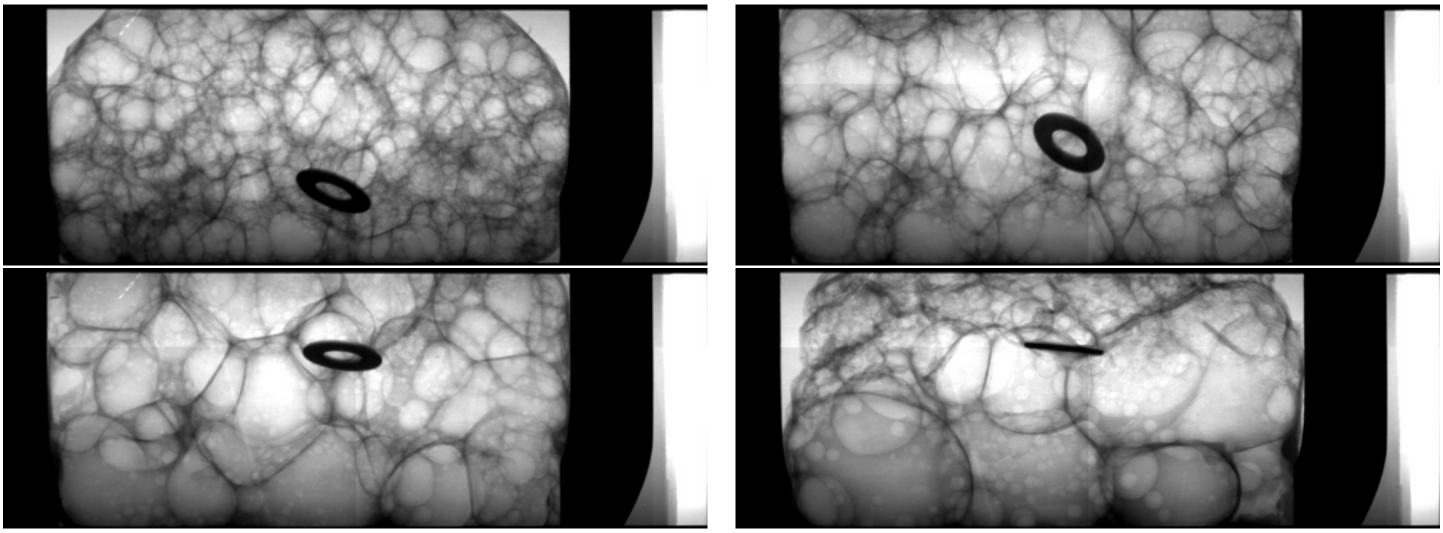

Figure 1: Evolution of foam expansion for a AlSi7 foam in a mould (furnace temperature $T = 700\,^{\circ}\mathrm{C}$). Foaming times are 2 min (top left), 2.5 min (top right), 3 min (bottom left) and 9 min (bottom right). The defect (a steel M2 washer) is supported by the foam structure.

For low temporal resolutions as realised in the experiment described above, the CCD was read out steadily with constant exposure times of 0.3 or 0.5 s resulting in image frequencies between 2 and 3 Hz. The entire foaming experiments grossly took a few minutes, corresponding to $500\ldots1200$ radiographs for each of the more than 100 individual experiments carried out.

For high temporal resolutions, the CCD read-out time limits the maximum steady-state frame rate which is achievable. The read-out time of a full frame of the Frelon 1000 camera (1024×1024 pixels) is 60 ms. This is a severe drawback for the investigation of fast processes such as rupture events of metal films or subsequent rearrangements.

The Frelon 2000 camera provides an exposure mode called "kinetics mode" which we applied for obtaining peak frame rates of up to 18 Hz. Using this operation mode, a region of the CCD can be reserved for image exposure, the remaining surface which is not exposed serves as image storage. After exposure of the reserved part of the CCD the electric charge can be shifted quickly to the shaded region dedicated for image storage. In this way, a fast series of images (usually $2, 4, 8, \ldots$) could be acquired and stored on the CCD. The maximum achievable frequency depends on the exposure time for one image and the shift time which is approximately proportional to the number of detector lines used for one image. We realised by this mode exposure times in the order of 50 ms and a vertical image size of 256 lines (and 2048 pixel horizontal width) translating into a shift time of about 5 ms. We accumulated four images on the CCD before read-out which allowed maximum frame rates of up to 18 Hz between the frames stored on the CCD. The mean frame rate is limited by the CCD read-out (240 ms) to 2.2 Hz in this case.

An example is given in Fig. 2 for an AlSi7 foam at a relatively high furnace temperature of $T = 775\,^{\circ}\mathrm{C}$. The left column shows a sequence of acquired radiographs, the right column the difference image between two successive frames in the left column. The difference images facilite the detection of changes between two images. Vanishing metal is shown in white in the difference images (right column), appearing metal in black. In this way film rearrangements are visible as black-white contrasted lines whereas ruptures are discernible as larger areas with light contrast (where metal disappeared) and dark contrast (where metal appears). Arrows highlight film rupture events and other changes.

The collapse of a large bubble on the right hand side of the first radiograph (just before the arbitrarily defined $t = 0$) is followed by a succession of film rearrangements and film ruptures. Over two subsequent frames ($t = 0$ and $t = 55$ ms) a bubble at the bottom border of the radiographs vanishes and films in the centre rearrange (see arrows in the corresponding difference images). Then, in frame $t = 110$ ms a film ruptures, followed again by film rearrangements (see black-white contrasted lines in the difference images during $t = 110\ldots415$ ms. Finally, at $t = 525$ ms a small bubble at the bottom of the frame disappears.

We see that it is possible to isolate different rupture events and reorganisation procedures taking place during foaming. The fast succession of rupture events suggests a causal connexion between them: if films get stretched too much — as caused by the large-scale collapse event between $t = -250$ ms and $t = 0$ — they become unstable and rupture. The rupture process itself takes less than 50 ms since in no case any sign of a smeared out cell wall has been observed in the acquired image sequence. In the case of Al alloy foams, the critical thickness of metal films just before rupture has been determined [SWW+02] to approximately 50 μm.

It would be very interesting to optimise the experimental set-up to achieve even higher frame rates and to store more frames on the CCD. In this way, exposure times in the order of 10 to 20 ms among 8 or 16 frames could deepen the understanding of metal film rupture and subsequent film reorganisation processes.

References

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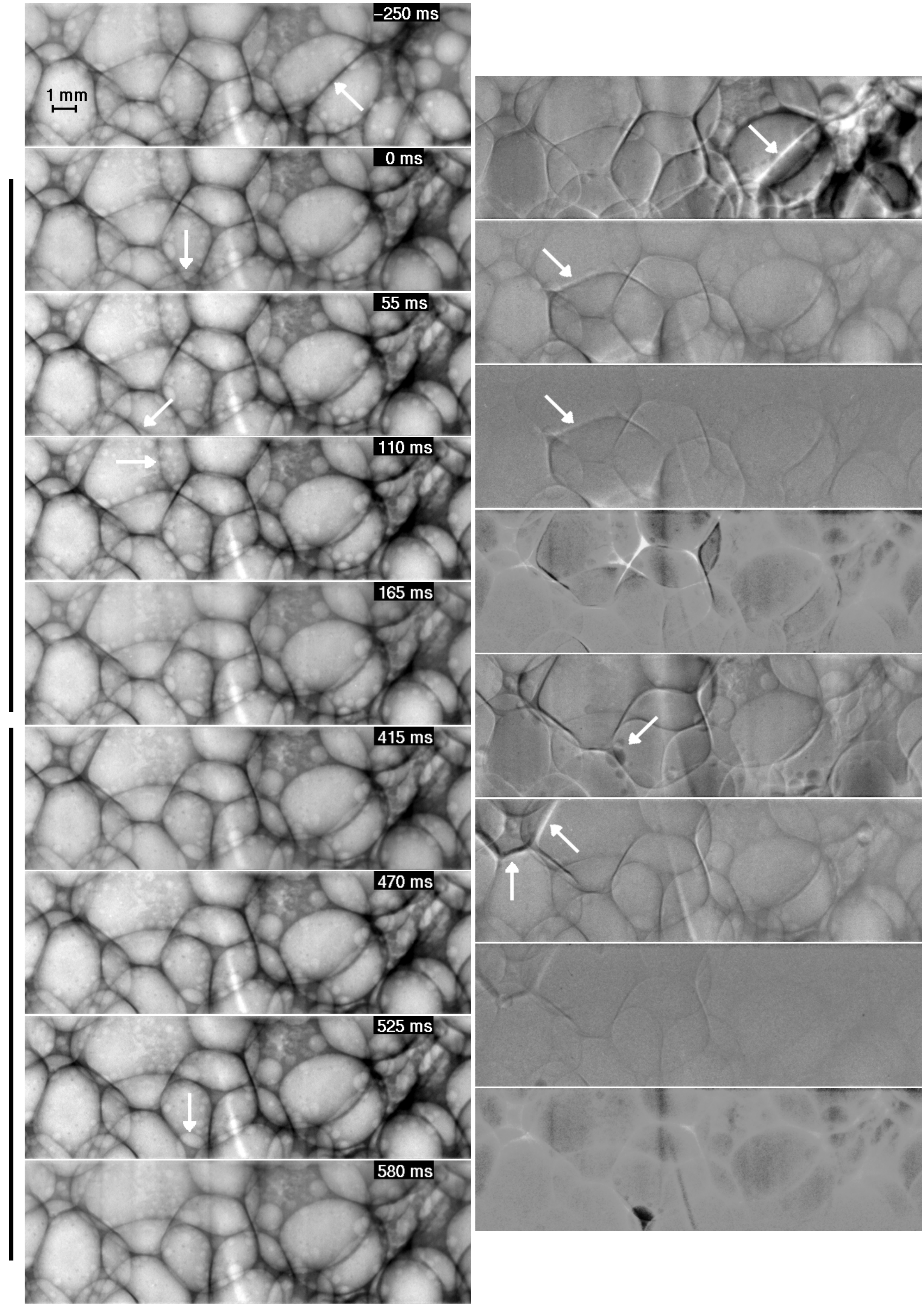

Figure 2: Fast radiography: The disappearance of the large bubble just before time $t_0 = 0$ is followed by a succession of topological rearrangements. The vertical lines mark sets of frames which have been accumulated on the CCD and read out at once. The difference images between two frames (right column, with time intervals of 250 ms between two sets) show the rearrangement of the liquid metal. Pixel size is 30 μm, furnace temperature 775 °C.