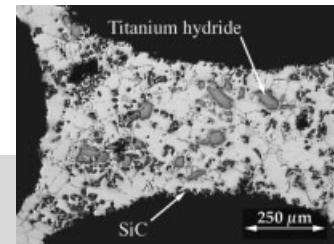


# The Effect of Prior Deformation on the Foaming Behavior of "FORMGRIP" Precursor Material\*\*

By Jeanette Frei, Vlado Gergely, Andreas Mortensen, and Bill Clyne\*

*It is shown that extrusion of "FORMGRIP" precursor material prior to baking leads to accelerated foaming and finer, more uniform cell structures. This effect is correlated with microstructural observations made on the precursor materials and on the foams. It is thought that, while extrusion apparently does not extensively fracture the gas-generating hydride particles, it does induce some damage to their protective surface oxide layers. Removal of the porosity normally present in as-cast precursors may also be beneficial.*



## 1. Introduction

There is current interest in closed cell Al-based foams for various applications<sup>[1-3]</sup>. Detailed studies<sup>[4-6]</sup> have been undertaken of the effects of cell structure on mechanical properties. There is a strong incentive to develop improved processing routes<sup>[7]</sup> for such foams, creating material having a fine, uniform cell structure (preferably without coarse, embrittling constituents<sup>[8]</sup>). Routes based on handling of a melt are cheaper and more tolerant of impurities than those based on a powder compact.<sup>[9]</sup> Techniques in which a gas-generating powder is dispersed throughout the melt produce finer and more uniform structures than those based on bubbling a gas into the liquid. A recently-developed procedure<sup>[10,11]</sup>, termed the "FORMGRIP" process (Foaming of Reinforced Metals by Gas Release In Precursors), in which a protective oxide coating is created on the surface of the powder (TiH<sub>2</sub>) particles prior to their incorporation in the melt, eliminates the problem of premature gas release during dispersion and allows a foamable precursor material to be created. This is subsequently baked in order to produce the foam.

Acceleration of the foaming process is an attractive aim, since it would reduce the time available for pore coarsening and allow production of finer, more uniform cell structures. A possible approach to this is to attempt to break up the gas-generating particles in the precursor in order to create direct contact between these and the metal, in turn rendering them more effective in generating voids. In the current paper, a

study is presented of the effect of prior mechanical deformation of the precursor on its foaming characteristics.

## 2. Experimental Procedures

### 2.1. Materials Used

DURALCAN F3S.10S type metal matrix composite (MMC) with 10 vol.-% of SiC particulate ( $9.3 \pm 1 \mu\text{m}$ ) was used for precursor/foam preparation. The particle aspect ratio is

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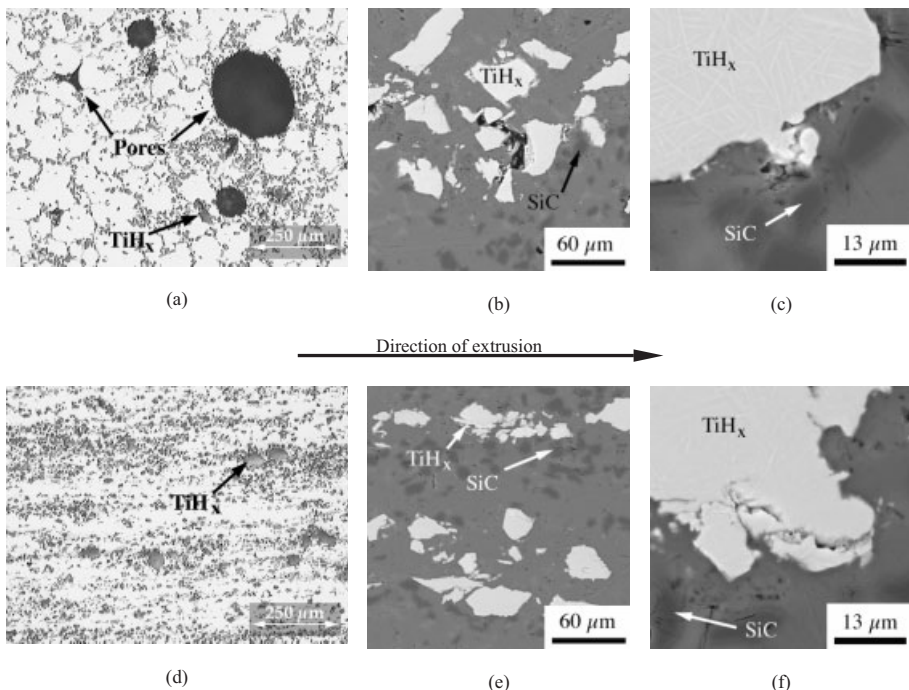


Fig. 1. Micrographs of FORMGRIP precursor material (10 vol.-% SiC<sub>p</sub>) showing the effect of prior deformation on the microstructure. (a) Optical and (b-c) Back-scattered SEM micrographs of as-cast material and (d) Optical and (e-f) Back-scattered SEM micrographs of extruded material.

about 1.5. The chemical composition of the matrix alloy is Al-9.0 wt.-% Si-0.55 wt.-% Mg, with other elements totalling less than 0.7 wt.-%. The liquidus and eutectic temperatures are 605 °C and 577 °C respectively.

Titanium hydride (TiH<sub>2</sub>) powder, supplied by Goodfellow's Ltd., UK, was used as a gas-generating agent. The average particle size was 45 μm, the purity 99.0% + and the density 3.9 Mg m<sup>-3</sup>. The as-received hydride was pre-treated, using a two stage thermal oxidation sequence in air (24 h at 400/C & 1 h at 500 °C) to generate a thin diffusion barrier layer (TiO<sub>2</sub>) on the powder surface and to alter the hydrogen concentration in the hydride<sup>[10]</sup>, which is designated TiH<sub>x</sub> after such treatment. The treatment ensures that there is minimal gas release during dispersion of the hydride in the melt and casting of the precursor.<sup>[11]</sup>

## 2.2. Preparation and Foaming of Precursor Material

Precursor production was carried out as described previously.<sup>[11]</sup> A charge of the composite material (~1 kg) was induction melted and heated to about 650 °C. The power was switched off and melt stirring (1200 rpm) imposed during cooling to 620 °C, using a mechanical impeller. The pretreated hydride powder (~1.5 wt.-% of the composite mass) was introduced into the melt at this point and the alloy stirred for a further 50–70 s. The precursor material was produced by allowing the melt to solidify. Some precursor material was then subjected to a further operation in which it was deformed in the solid state. This was carried out using the

direct extrusion method, with an extrusion ratio of 10 (from 19 to 6 mm diameter), at a temperature of ~355 °C.

Foaming experiments were carried out in an electrical resistance tube furnace. Precursor specimens, 6 mm in diameter and about 20 mm tall, were located along the axis of a vertical quartz tube, resting on a graphite support. The quartz tube was 15 mm in diameter, thus giving ample room for the precursor to expand sideways. The mould was also tall enough to allow free expansion of the foams in the vertical direction. The mould was placed into the furnace, which was preheated to 650 °C. The precursors were heated to 630 °C and then held at this temperature for a period of 30, 60, 120, 250, or 300 s, while recording the temperature with a thermocouple embedded into the sample near its lower surface. Thermal decomposition of the hydride was thus induced and the evolving

gas foamed the melt. After the specified time, the moulds were removed from the furnace and the foams were allowed to solidify. In selected experiments, the expansion of the precursor was filmed through the quartz tube within the tube furnace, using a digital video camera.

## 3. Effect of Deformation on the Precursor Microstructure

The microstructures of as-fabricated and extruded precursors, containing 10 vol.-% SiC<sub>p</sub>, are shown in Figure 1. The SiC particles have been pushed into the interdendritic regions during solidification, causing clustering in the as-fabricated precursor (Fig. 1a). The Al-Si eutectic structure is fairly coarse, as a consequence of the relatively slow cooling during

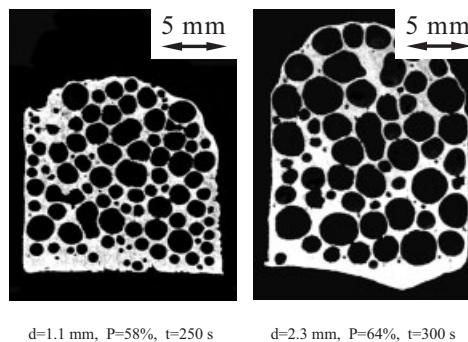


Fig. 2. Optical micrographs of vertical sections through F3S.10S foams produced using as-cast precursor material, showing how the dwell time (t) at the foaming temperature (~630 °C) affects the average cell size (d) and the porosity (P).

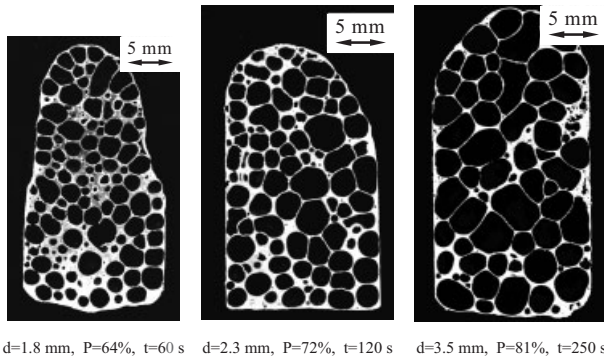


Fig. 3. Optical micrographs of vertical sections through F3S.10S foams, produced at  $-630^{\circ}\text{C}$  using extruded precursor material, showing measured average cell sizes ( $d$ ) and porosity levels ( $P$ ).

precursor solidification, so the Si platelets are similar in size to the SiC particles. This material also exhibits a significant level of porosity ( $\sim 15\%$ ), predominantly the result of a small amount of gas release from the hydride foaming agent.

Extrusion generates an effectively pore-free material, with the particles (Si, SiC, and  $\text{TiH}_x$ ) becoming aligned in the extrusion direction (Fig. 1d). There is evidence (Fig. 1f) that  $\text{TiH}_x$  particles become damaged during extrusion. This apparently involves some fracture, but it also seems likely that the extensive shear to which the matrix-particle interface was subjected during extrusion has generated local damage, probably involving disturbance to the protective oxide layer.

#### 4. Effect of Deformation on Foaming Characteristics

Sections through foams produced by baking as-cast and extruded precursors are shown in Figures 2 and 3. Average pore levels and sizes in the foams are also shown in these figures. The porosity and cell size evolution during foaming, for both types of precursor, is plotted in Figure 4. It is clear from these figures that the prior extrusion operation produces precursor material which foams more rapidly. This is a considerable advantage in practical terms, since it means that drainage and cell coarsening effects will tend to be less pronounced. Also, combinations of high porosity and fine cell sizes can be achieved more readily with the extruded precursor material. For example, a 65% porous foam is produced after about 60 s with the extruded material, at which point the cell size is below 2 mm. In contrast, it takes over 300 s to reach this porosity level with the standard precursor, by which time the cell size is almost 2.5 mm. There would also be economic advantages in reducing the baking period.

Filming the precursor within the tube furnace through the quartz tube showed that prior deformation of the precursor exerts a significant influence on the course of the foaming process. As it was heated to  $630^{\circ}\text{C}$ , the undeformed precursor sample first slumped to less than half its original height, and then rose again. The extruded precursor, on the other hand,

did not slump significantly, but rather expanded sideways, and then upwards, from the onset of the foaming process.

Representative cell wall microstructures are shown in Figure 5. Clusters of unreacted hydride particles, were noticeably more common in foams produced using the as-cast precursor material than in foams produced from the extruded precursor (compare Fig. 5a with Fig. 5b). It seems likely that fragmentation of the hydride particles, and of their diffusion barrier surface layer, was primarily responsible for the more efficient foaming action observed with the extruded material. Removal of the rather coarse porosity present in the as-cast precursor material may also have been beneficial, since these large pores probably promote accelerated pore coarsening early in the foaming process and may inhibit the dispersed generation of new pore nuclei. Further work is needed to ascertain the relative importance of this mechanism, compared with that of damage to the hydride particles or interfacial regions.

#### 5. Conclusions

It has been shown that prior mechanical deformation of "FORMGRIP" precursor material in the solid state alters its foaming behavior, accelerating the process and facilitating the production of foams with higher porosity levels and finer, more uniform cell structures.

The extrusion operation generates a more uniform distribution of ceramic particles, including the gas-generating  $\text{TiH}_x$  particles, and also virtually eliminates the moderate porosity levels ( $\sim 15\%$ ) commonly found in as-cast precursor material. Foams produced from as-cast precursors contained unreacted clusters of  $\text{TiH}_x$  particles within the cell walls; these were far less common in foams made from deformed precursors.

It appears likely that the improved foaming efficiency is at least partly due to an improved distribution of gas-generating particles within the precursor. Moreover, there was

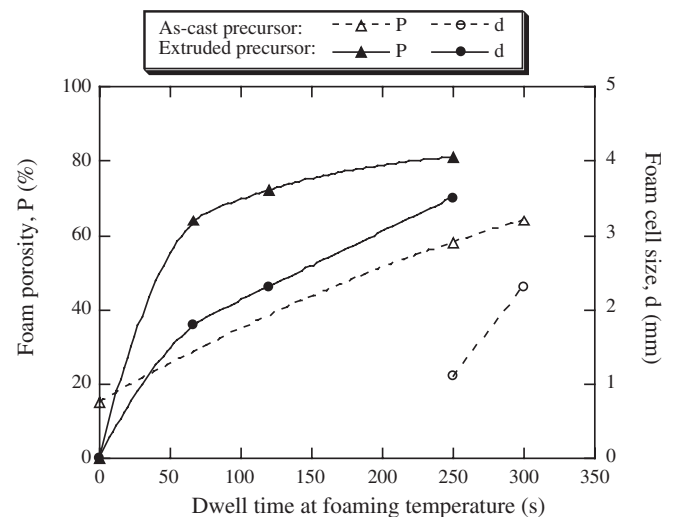


Fig. 4. Plot showing the effect of prior precursor deformation on the rate of evolution of porosity and cell size during baking at  $630^{\circ}\text{C}$ .

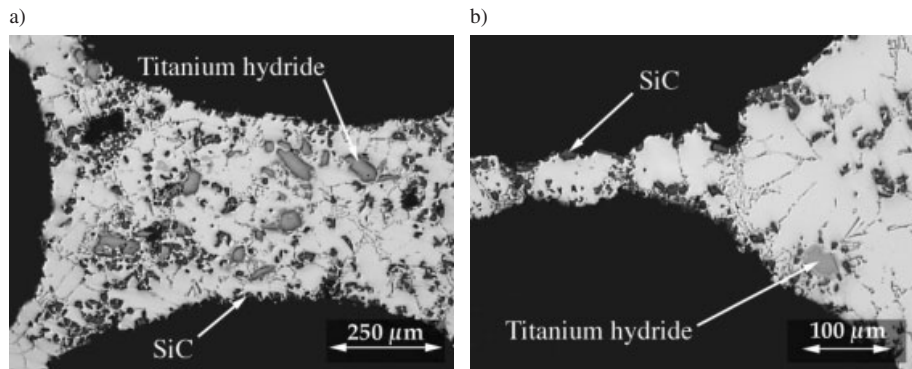


Fig. 5. Optical micrographs showing the cell wall microstructures of 10 vol.-% SiC<sub>p</sub> foams, produced by baking of a) as-cast and b) extruded precursors.

some evidence that the extensive shear induced at the hydride interfaces with the matrix during solid state deformation induces damage to the protective oxide layers and causes fracture of hydride particles. Direct hydride-to-metal contact thus created within the deformed precursor may be a cause for the observed accelerated gas release during foaming.

The present data also suggest that the removal of the prior porosity in the precursor may have a beneficial effect by encouraging more dispersed nucleation of pores and preventing accelerated early pore coarsening.

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