Semi-solid processing of complex-shaped foamable material

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A hybrid process comprising aspects of casting and powder technology is used for the production of complex shaped foam precursor material. Powder mixtures of aluminium alloys and foaming agent are cold-isostatically compacted to cylindrical slugs which are then heated to the semi-solid state and processed in conventional cold-chamber high pressure die casting machines. This approach offers a highly productive method to produce foamable precursors with almost arbitrary shapes, e.g. with holes, changing wall thicknesses, or other geometric complexities. Due to the nature of the casting process an improved pore morphology has been observed. This can be explained by the comparably isotropic microstructure of the castings and an in-situ heat treatment of the foaming agent.

1 Introduction

Among the various technologies for the production of metal foams [1] the powder-metallurgical approach [2,3] has attracted the most scientific and industrial interest due to its flexibility with respect to the choice of alloys and the possibility to produce relatively complex shaped foam and sandwich components. Nevertheless, wide scale industrial production has not yet been achieved as the following essential prerequisites still have to be fulfilled: further improvement of the understanding of the process - especially regarding the behaviour of the foaming agent and its interaction with the metal matrix and the mechanisms of foam collapse - , securing of a homogeneous and reproducible quality of the precursor material and the reduction of the precursor and the overall process costs.

An example for the deficiencies of the current technology is the common appearance of macro-pores, see Fig.1, whose formation is attributed to the typical anisotropic microstructure of extruded or uni-axially hot-pressed precursor material and the high decomposition pressures of the standard foaming agent TiH_2 near the solidus temperature of the alloy. This leads to a crack-like appearance of pores in the early foaming stages and to large-scale heterogeneities during further foaming..

Another current drawback are the high costs of the foams produced in this way. The main cost drivers are: the use of powder metals, the extrusion process and the foaming moulds. The situation is even worse in the production of complex shaped metal foam components as the extruded precursor has to be adapted to the mould geometry which requires further cost intensive forming or cutting steps. A possibility to avoid this is to use simple-shaped precursors and rely on the flowing ability of the liquid metal foam during expansion. This might, however, lead to inhomogeneous heat transfer conditions (especially with precursor granulate), a deterioration of the foam structure during the flow process and the inclusion of oxide skins into the components. As a consequence a casting process would be advantageous for the production of such complex shaped precursor materials.

Fig. 1. Inhomogeneous pore structure with macro-pore in AlSi7 foam made from extruded precursor material

A new hybrid casting-powder metallurgical process for the production of metal foam precursor material has been developed based on thixocasting of cold-isostatically compacted powder mixtures [4]. The principles and features of this approach will be explained and discussed in comparison with state-of-the art technologies such as extrusion and uni-axial hot-pressing.

2 Technological approach

The developed approach is principally based on the thixocasting process, see e.g. [5] or [6], though in this case powder mixtures compacted to slugs are used instead of direct cast pre-material. The process comprises the following steps:

- Mixing of metal powders and foaming agent powders (e.g. aluminium, silicon, TiH_2),
- cold-isostatic compaction to cylindrical slugs,
- heating of the slugs to the semi-solid state
- thixocasting by means of a vertical or horizontal cold-chamber high-pressure die casting machine
- removing from the casting mould and removal of overflows
- foaming

The complete process is represented in Figure 2.in comparison with the “traditional” PM extrusion technology.

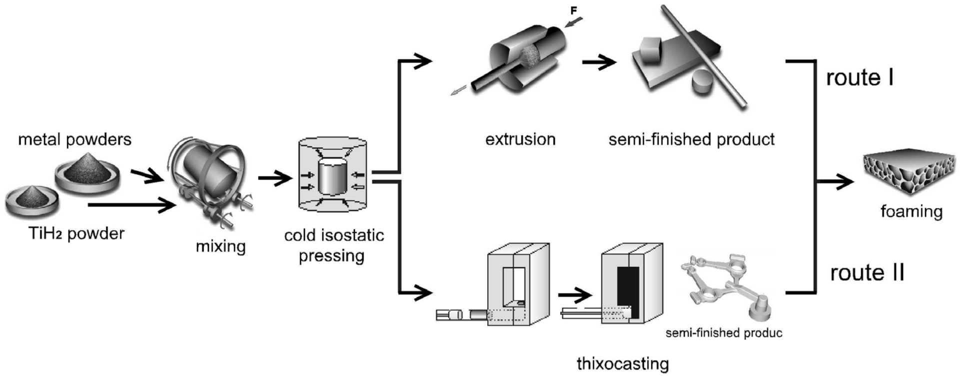

Fig. 2. Comparison of the process steps for the production of metal foams by means of powder compaction and extrusion ("route I“) and thixocasting ("route II“)

3 Comparison and evaluation of the processes

The metal powders and the foaming agent were mixed for 45 minutes and cold-isostatically compacted at 150 MPa. The resulting billets were subsequently heated in an annealing furnace into the semi-solid state. The heating parameters varied with the alloys (duration 40-60 minutes, temperature 590 °C-620 °C). Because the foaming agent is subjected to an in-situ heat treatment during heating, the experiments had to be restricted to comparatively low melting standard casting alloys such as AlSi6Cu4, AlSi11 and AlZn5,5MgCu. For alloys with higher melting temperatures the semi-solid process temperatures would lead to a too rapid decomposition of the foaming agent. The content of the foaming agent in the different powder mixtures was varied between 0.5 and 1.5 wt.% for the different alloys.

After heating the semi-solid slugs were manually transferred into the sleeve of the Bühler SCN/66horizontal cold chamber high pressure die casting machine and pressed into the die cavity. The locking force of the die casting machine was 6615 kN. A mould optimised for conventional thixocasting was used. The mould was equipped with pressure sensors in the casting system and in the component cavity. The test component, a connecting rod, demonstrates typical features of castings such as varying wall thickness, cores and shrinkage restrictions. The smallest wall thickness was 5 mm in a distance of approximately 420 mm from the biscuit. The typical shot weight was 1,5-1,7 kg. The metal front velocity during the filling was approximately 1-2 m/s and the secondary compression pressure 150-190 MPa.

The microstructures of thixocast and extruded AlSi6Cu4 precursor material are compared in Fig. 3. The most distinct feature is the isotropy of the thixocast material in comparison with the layered structure of the extruded precursor.

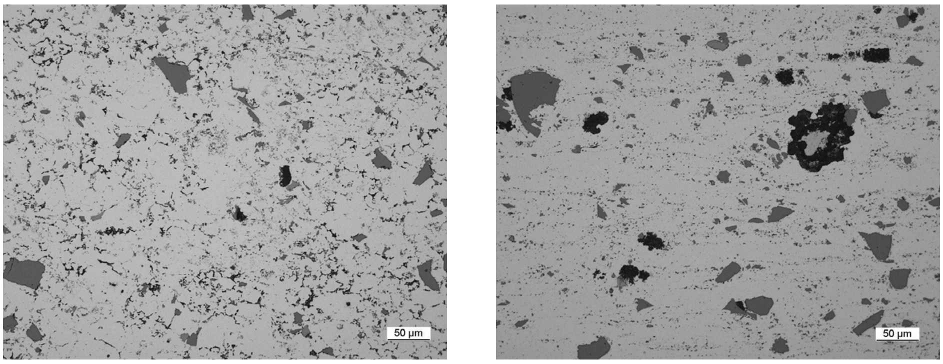

Fig. 3. Comparison of the microstructure of thixocast (left) and extruded (right) foamable metal, in both cases alloy AlSi6Cu4

Thixocast AlSi6Cu4 precursor specimens were used for in-situ radioscopy experiments, the details of which can be found in [7]. The main results were the following: thixocast precursor materials

- expand at higher temperatures, i.e. when the matrix is softer,
- show no crack-like pores in the early foaming stages, see Figure 4,
- have a lower maximum expansion,
- have a higher coalescence activity and,
- show a more pronounced collapse behaviour.

These features were confirmed in expandometric experiments and can be attributed to the isotropic structure of the precursor. Furthermore, the in-situ heat treatment of the foaming agent during the semi-solid processing leads to reduced decomposition pressures during the early foaming stages. The high coalescence activity is attributed to a reduced efficiency or content of foam stabilizing components in comparison to extruded or uni-axial hot pressed material.

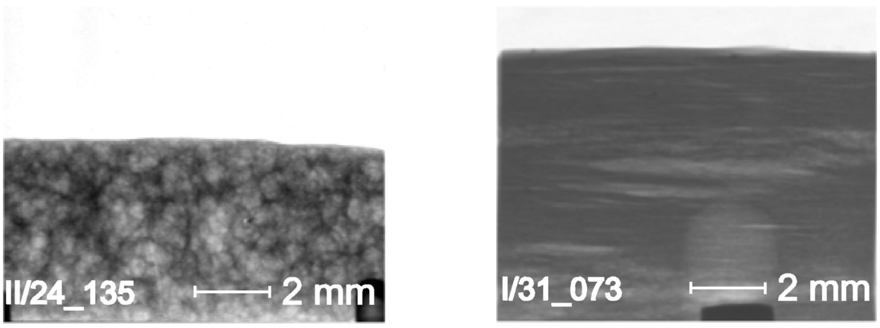

Fig. 4. Comparison of the foaming behaviour of thixocast (AlSi6Cu4+0,5 wt% TiH_2, left) and uni-axial hot-pressed (AlSi7 + 0,5 wt% TiH_2, right) precursors [7]

As can be seen in Figure 5, the thixocast precursor material can lead to homogeneous pore structures in the resulting foam. A further improvement of the foam structure can be expected if measures (e.g. the addition of special alloying components) against the high coalescence activity can be found.

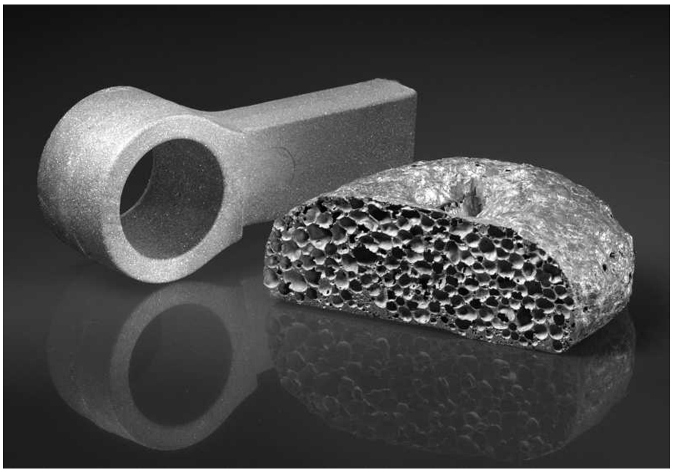

Fig. 5. Parts of a thixocast precursor material before and after foaming

As the thixocasting route secures a more isotropic microstructure of the precursor material the use of alternative and less expensive starting materials unsuited for extrusion was tested. The primary metal powder (costs approx. 3.50 €/kg) was substituted by AlSi7Mg-recycling material (sorted and thermally cleaned cutting chips from wheel production, supplied by Oetinger, Germany, 1.30 €/kg). These AlSi7Mg-chips were mixed with various powder blends (Al, pure + 10-20 wt%TiH_2) adjusting the relatively high TiH_2-content of 1,5 wt%. The mixture was heated in ambient atmosphere for 60 minutes at temperatures between 200 and 400 °C. Different heating temperatures were chosen in order to facilitate the following uni-axial compaction to cylindrical slugs and to obtain different degrees of superficial oxidation of the chips. The compaction was carried at various pressures in a pre-heated sleeve (200 °C) of a cold-chamber high pressure die casting unit as for the compaction of chips the large stroke length (600 mm) of this machine is advantageous. After this the slugs were heated to the semi-solid state and were then thixocast. To increase shearing during mould filling metallic meshes were fixed into the sleeve of the HP die casting machine. Metal front velocities of 2-3 m/s and intensification pressures of 1250-1500 bar were used.

As can be seen in Figure 6, left, the pore structure of foams produced from thixocast recycling material is quite coarse and inhomogeneous. This is attributed to the inhomogeneous distribution of TiH_2 in the precursor material (see Fig. 6, right) and to a lower oxide content of the cutting chip slugs in comparison to compacted powder mixtures.

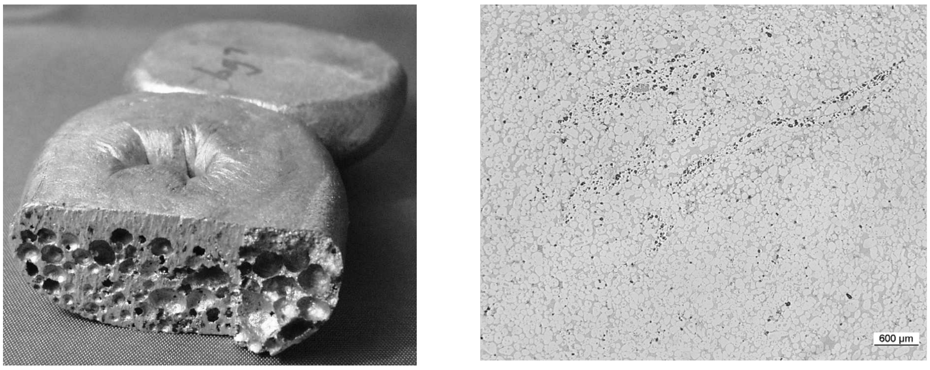

Fig. 6. Pore structure of AlSi7Mg-foam made from recycling precursor material (left) and TiH_2-distribution in thixocast AlSi7Mg recycling precursor (right)

4 Summary and outlook

The presented semi-solid process for metal foam precursor material allows us to produce complex shaped precursor components with isotropic microstructures resulting in comparatively uniform pore structure of the corresponding metal foams. In order to fully exploit the advantages of this technology, the influence of process parameters such as the heating temperature or the casting velocity on the resulting foam structure has to be better understood. This is currently subject of a project funded by the DFG.

Acknowledgements

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