Metallschäume: Proc. of Symposium Metallschäume, Bremen, 6.-7.03.1997
Ed. by J. Banhart, MIT Verlag, Bremen, 1997, p. 171 - 176

# Porosity in complex 3D-parts prepared from aluminium foam

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## Abstract

Porous structures of the complex-shaped samples cast from aluminium foam have been studied. The apparent density, pore size, pore shape, pore orientation and their distributions in various cross-sectional areas of the experimental samples have been investigated with respect to the manufacturing of the samples. It is shown that the characteristics significantly depend on the preparation of the foam before casting.

## 1. Introduction

Since 1957 a great benefits have been expected from the unusual properties of aluminium foam [1]. However, aluminium foam did not find any important industrial application up to now, despite lots of research and experimental work done on this subject. One of the major obstacles in its utilisation has been the impossibility of preparing shaped foamed parts with a certain reproducibility of structure and properties at acceptable costs. A new proprietary technique [2], has recently been developed by the company Illichmann GmbH in close cooperation with the Institute of Materials & Machine Mechanics SAS. This method could be a possibility of how to overcome these problems in the future.

The technique combines powder metallurgical [3] and casting methods and has been developed for a later series production of complex-shaped foamed parts. The foam is being prepared in the special device from powder metallurgical, simple shaped foamable precursor and then cast (injected) into the mould cavity of the desired shapes. Even sand moulds and sand cores can be used for this purpose, thus enabling cost effective small scale production and prototyping. The foamed parts are normally covered by a dense aluminium skin which significantly improves the mechanical properties and metallic appearance of the foam (Fig.1).

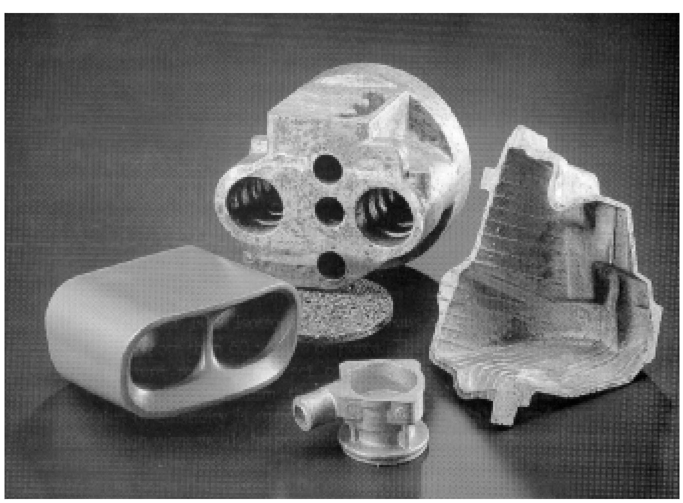

*Fig. 1: Various 3D parts prepared from aluminium foam.*

With castings typically having complicated shapes and varying wall thickness, differences in the pore size and in the apparent density can be expected in various cross-sections of the foamed parts. The aim of this paper is to study the porosity of the cast foamed samples and to make suggestions for the improvement of its uniformity with respect to the distribution of the apparent density, pore size and pore orientation.

## 2. Experimental

Existing moulds for an aluminium waterpump casting (volume of 75 $cm^3$) have been chosen as samples for the tests (Fig.2). The samples have been cast into sand moulds with sand cores (Cold Box), using aluminium foam prepared from a precursor based on AlSi12-powder mixed with 0.4 wt% $TiH_2$. The pore size, density and volume of the molten foam have been optimised before the injection in order to obtain a homogeneous porosity in the casting. The cast parts have been cut in two cutting planes (Fig.2) by electric discharge machining in order to reveal the inside porosity of the various cross-sections of the sample. The porous cutting areas have been painted black and polished afterwards in order to obtain a good contrast between the pores and the pore walls. The structure then has been scanned with a 600 dpi scanner (1 dot represents an area of about 0.0064 $mm^2$) and evaluated by computer image analysis (Image Pro Plus Fy. Media Cybernetics). The cross-sections of the sample have been divided into 5 different regions (see Fig.2). The following characteristics have been determined in the corresponding regions according to [4]:

- number of pores
- average pore size (in 2 dimensions)
- image density (square fraction of the pore walls in investigated area multiplied by the density of the bulk material)
- aspect ratio of the pores (ratio between the minor and the major axis of the equivalent ellipse)
- pore orientation (orientation of the major axis of the equivalent ellipse)

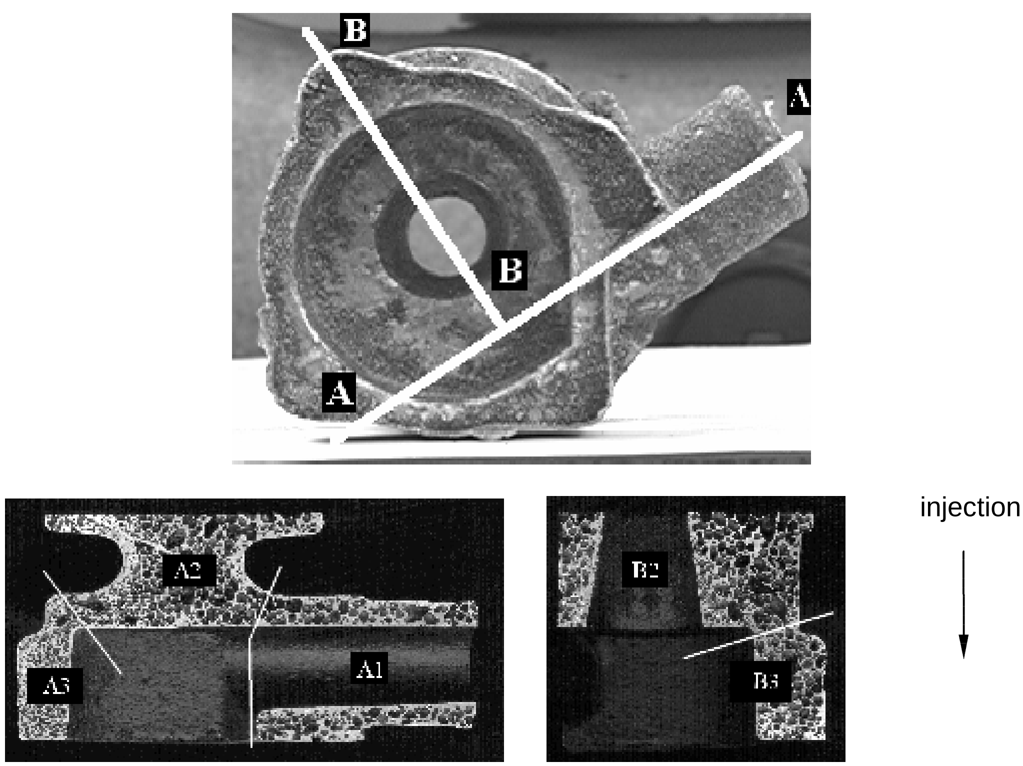


*Fig. 2: Cutting planes and borders of regions for image analysis.*

## 3. Results and Discussion

The porous structures of four experimental samples are revealed in Fig.3. The computed characteristics for each region are listed in Table 1. It can be seen that in all cases the image density is much higher than the values obtained from a weight/volume calculation (apparent density). This is caused partially by metallographic preparation, which makes it difficult to exactly reveal the pore structure, and partially by the image processor neglecting the fine pores. However, the image density values can still be successfully used for the evaluation of the density distribution inside the sample.

The structure of the foam before injection can be derived from the structure of region A3. This region represents the cross-section of the casting where the injected foam solidifies almost immediately. The average pore size in this region corresponds well with the apparent density of the foam before injection.

The apparent density of the sample No. 51 is lower than the apparent density of the foam before injection. This means that the foam after injection still goes expanding inside mould. This further expansion in complex-shaped moulds is only possible in regions with somewhat larger cross-sections where the foam still being liquid does not solidify immediately. This can lead to a non uniform density and pore size distribution of the sample (see CV for sample No. 51 in Table 1). On the other hand this inhomogeneity is sometimes acceptable, especially when the concerned areas should be strengthened by the higher density of the structure.

An increase in the foam volume to be injected means a higher external pressure which limits the additional expansion of the foam inside the cavity leading to approximately the same pore structure as in the foam before injection. If the foam structure before injection is homogeneous with respect to density and pore size distribution, the pore structure of the cast part also remains uniform. The best uniformity of all pore structures has been determined for samples No. 50 and No. 29 (see CV for pore size and density in Table 1). In these cases, foams with different apparent densities but with equal volumes have been used for injection. The resulting densities of the cast parts do not differ significantly from the density of the foam before injection. However, the sample cast from lower density foam (sample No. 50) possesses a larger pore size than the other one (sample No. 29).

If the foam volume to be injected is too high, it cannot be injected completely into the mould. The resulting increase of the external pressure (see above) leads to the compression and collapse of the pores in the regions, where the foam is still liquid. The obtained structure is therefore very inhomogeneous (see CV for sample No. 31 in Table 1). Additionally, the overall apparent density of the sample (weight/volume ratio) is considerably higher than the density of the injected foam.

Computer analysis reveals that these pores are to some extent compressed having an average aspect ratio lower than 1 (see Table 1). The lowest aspect ratio was usually found in the region A1. In this area of the sample the liquid foam is forced into the tube-shaped and thin-walled cavity. This leads to the pores being preferentially orientated parallel to the axis of the tube (see Fig.4). Nevertheless, the differences in the aspect ratio are not significant (see CV for aspect ratio in Table 1).

The highest average aspect ratio was found for sample No. 51. This means that the shapes of the pores in this sample are having minimum deformation compared with other samples. This fact verifies the assumption that the foam is allowed to expand inside the mould in case the external pressure due to a lower charge volume is low enough.

Except region A1, the orientations of the pores in the samples investigated are generally pretty random (see Fig.4). An increasing external pressure leads to a slight compression of the pores of the gate area (region A2) having a low aspect ratio. In this case the preferential orientation of these pores is perpendicular to the direction of injection. Again, the orientation of the pores of the sample with lower injected volume (sample No. 51) is more random than the sample with a higher injected volume (sample No. 28).

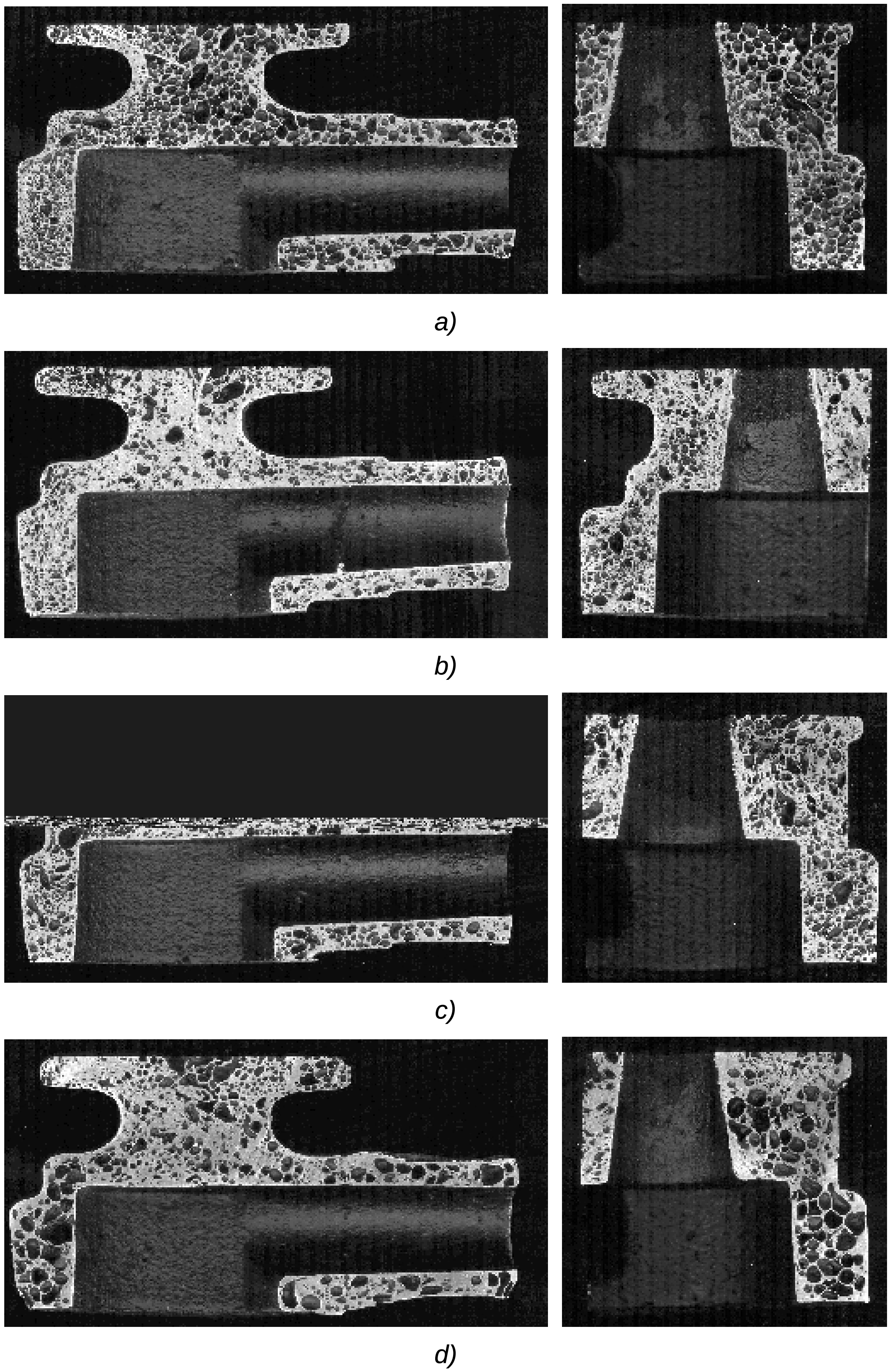


*Fig. 3: Porous structures of experimental samples No.: a) 51, b) 29, c) 50 and d) 31.*

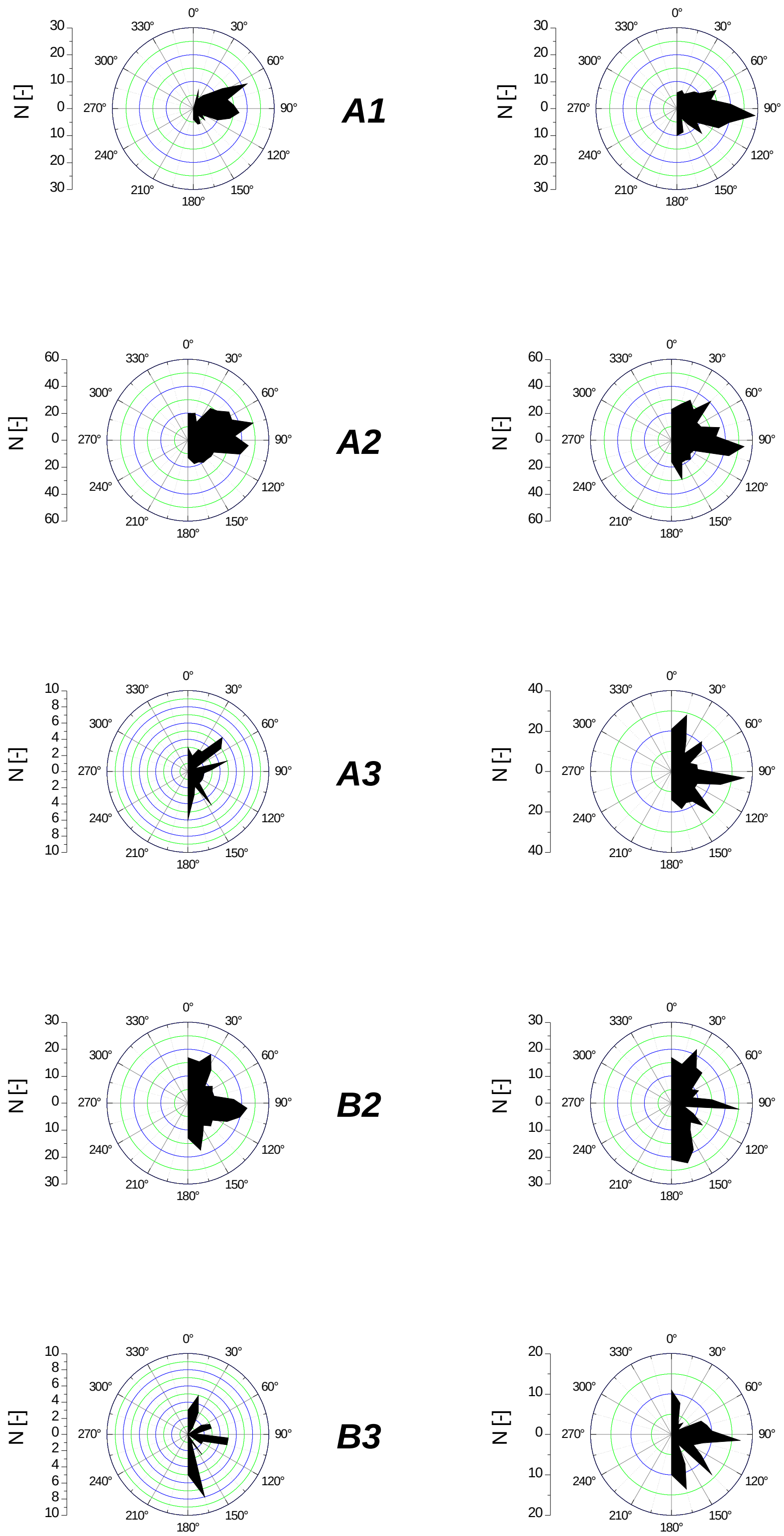


*Fig. 4: Orientation of the pores in the various regions for the samples No. 31 (left) and No. 51(right).*

*Table 1: Characteristics of the porous structure of the specimens cast from aluminium foam. (the structures and regions are illustrated in Fig.2 and Fig.3)*

| sample | | foam before injection | | density of the sample | | pores (average values) | | |
|---|---|---|---|---|---|---|---|---|
| No. | region | density | volume | volumetric | image value | number | size | aspect ratio |
| | | $gcm^{-3}$ | $cm^3$ | $gcm^{-3}$ | $gcm^{-3}$ | | $mm^2$ | |
| **51** | **A1** | | | | 1.333 | 214 | 0.954 | 0.683 |
| | **A2** | | | | 1.170 | 514 | 0699 | 0.720 |
| | **A3** | | | | 1.435 | 355 | 0.289 | 0.731 |
| | **B2** | | | | 1.087 | 269 | 1.209 | 0.680 |
| | **B3** | | | | 1.110 | 149 | 0.968 | 0.715 |
| | **mean** | **1.0** | **100** | **0.613** | **1.227** | **1501** | **0.824** | **0.706** |
| | **CV[%]** | | | | **12.2** | | **42.0** | **3.3** |
| **29** | **A1** | | | | 1.929 | 295 | 0.367 | 0.583 |
| | **A2** | | | | 1.837 | 516 | 0.363 | 0.636 |
| | **A3** | | | | 1.867 | 239 | 0.275 | 0.603 |
| | **B2** | | | | 1.881 | 454 | 0.320 | 0.661 |
| | **B3** | | | | 1.607 | 280 | 0.362 | 0.648 |
| | **mean** | **1.0** | **130** | **0.907** | **1.824** | **1784** | **0.337** | **0.626** |
| | **CV[%]** | | | | **6.9** | | **11.8** | **5.2** |
| **50** | **A1** | | | | 1.648 | 244 | 0.623 | 0.705 |
| | **A2** | | | | 1.482 | 489 | 0.582 | 0.683 |
| | **A3** | | | | 1.596 | 199 | 0.447 | 0.702 |
| | **B2** | | | | 1.556 | 420 | 0.575 | 0.656 |
| | **B3** | | | | 1.433 | 187 | 0.624 | 0.702 |
| | **mean** | **0.8** | **130** | **0.853** | **1.543** | **1539** | **0.570** | **0.690** |
| | **CV[%]** | | | | **5.6** | | **12.7** | **3.0** |
| **31** | **A1** | | | | 1.637 | 159 | 0.964 | 0.631 |
| | **A2** | | | | 1.674 | 496 | 0.582 | 0.637 |
| | **A3** | | | | 1.167 | 58 | 2.299 | 0.687 |
| | **B2** | | | | 1.598 | 262 | 0.853 | 0.667 |
| | **B3** | | | | 1.162 | 53 | 2.554 | 0.739 |
| | **mean** | **0.7** | **150** | **1.033** | **1.448** | **1028** | **1.450** | **0.672** |
| | **CV[%]** | | | | **18.0** | | **62.5** | **6.5** |

*CV - the coefficient of variation.*

## Conclusions

The study of the pore structure of aluminium foam samples made by our casting technique has revealed that the complex-shaped parts showing good homogeneity with respect to pore size and density distribution can be obtained. The structure of the part is significantly influenced by the conditioning of the foam before injection.

## Acknowledgement

Thanks are due to Illichmann GmbH, Altmünster, Austria for funding this work.

## References

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