# Characterization of cast and compressed foam structures by combined 2D-3D analysis

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## Abstract

In this work a 2D-3D characterization routine is presented for an open-cell aluminium foam produced by investment casting. The new 2D-3D characterization routine uses a microtomograph as a non-destructive testing tool besides the conventional 2D route by preparing cross-sections. Main topics are the comparison and the combination of both analysis routines to improve the structural characterization. Important aspects of 2D structure evaluation are fragment analysis and object fitting routines by which macroscopic and microscopic cell parameters can be analized. Cell tracking and homogeneity aspects are part of the 3D routine.

## 1 Introduction

There exist a number of routes to produce cellular metallic materials. They are based on different metallurgical, physical, chemical and electro-chemical processes and make open, closed and mixed cell foams. The attained properties are far from the theoretically ideal values. To achieve better a better understanding of the structure-properties-correlation an improvement of the foam characterization is needed. Up to now no detailed characterization of the foam structure is available for cellular metallic materials because the complex structure limits commonly used 2D characterization techniques.
A detailed characterization of the metallic open-cell material contains the analysis of the geometric structure and microstructural composition, that are of interest when applying the theoretical structure-properties-correlation. For this purpose the conventional 2D micrograph is of limited use. An exact description of cell structures is expected from a 3D non-destructive structural analysis. With this it will be possible to correlate the structure and the mechanical properties and to verify theoretical models of the cell structure. Furthermore, there is the possibility of optimizing the production process and to match the geometric structure to special applications.

## 2 Development of new characterization approaches

The characterization of an open-cell foam adresses not only the geometric structure (macroscopic and microscopic) but also the microstructural composition of cell walls and cell nodes. At each of these levels, we define parameters that form the set of parameters for the detailed characterization of open-cell structures (Table 1).
In detail, porosity, average cell size, distribution in cell size and arrangement of cells serve to characterize the macroscopic aspects of the sample. The microscopic analysis refers to the open-cell pores, where the size and shape of cell walls are used to describe the enclosed airspace.

J. Banhart, M.F. Ashby, N.A. Fleck: *Metal Foams and Porous Metal Structures.* © MIT Verlag (1999)

Table 1: The set of parameters used to characterize open-cell structures is based on different digital imaging techniques. The parameters are measured with different evaluation methods.

| characterization part | structure parameter | digital imaging technique | evaluation / analysis routine |
|---|---|---|---|
| macroscopic structure | porosity | light microscope or scanner resp. microtomograph | fragment analysis |
| | average cell size | | object fitting |
| | distribution in cell size | | |
| | cell arrangement (gradient, homogeneity,orientation) | microtomograph | cell arrangement |
| microscopic structure | cell wall / cell node size | light microscope or scanner resp. microtomograph | fragment analysis |
| | cell wall / cell node diameter | | |
| | cell wall / cell node shape | | |
| | cell size | | object fitting |
| | cell diameter | | |
| | cell shape | | |
| | cell volume (3D) | microtomograph | cell tracking |
| materials structure | microstructure | scanning electron microscope | |
| | surface | | |
| | composition | | |

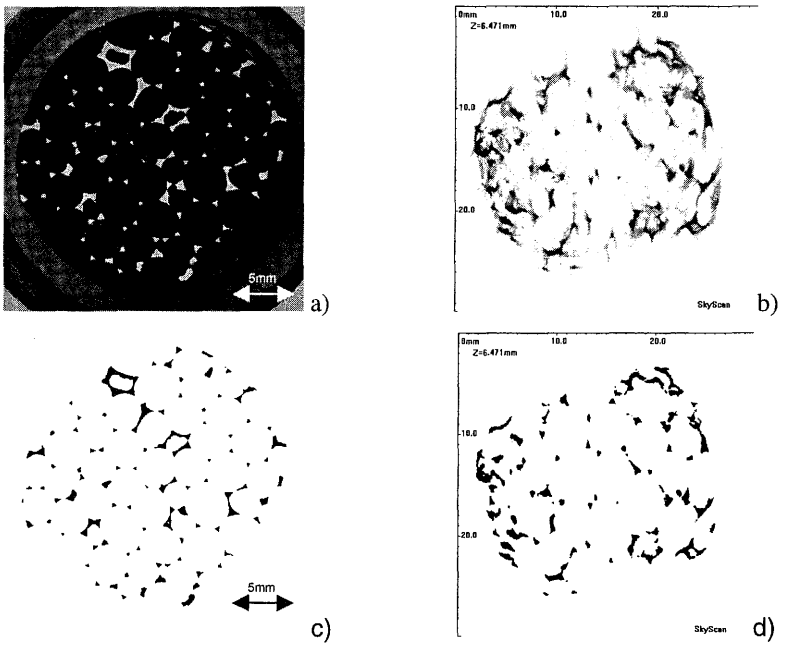



Fig. 1: The images illustrate the comparison between conventional cross-sections (a & c) and tomography images (b & d) in digitized (a & b) and binarized (c & d) modes.

The parameters are measured with different digital imaging and analysis techniques. A central part of the evaluation of the macroscopic and microscopic parameters is a fast digital image analysis system (Zeiss/Kontron KS400). Interesting macroscopic and microscopic parameters are determined and judged on cross-sections made by conventional 2D preparation techniques as well as by use of microtomography. Conventionally ground and polished samples require a previous preparation: The pores of the open-cell material are filled with coloured epoxy resin to provide sufficient contrast and to minimise damage of the cell structure. With a scanner each cross-section is digitalized (Fig. 1a) and binarized (Fig. 1c). On the other hand, microtomography demands no previous preparation of the sample. Unlike conventional cross-sections the tomograph delivers any cross-section of the sample (Fig. 1b). The tomography images are binarized again with a special algorithm of the digital imaging system (Fig. 1d). Based of these binarized tomographic images it is possible to realize a 3D reconstruction with the help of different reconstruction techniques such as the gradient shading method [1]. Such a 3D-reconstruction enables a physical visualization of an open-cell foam (Fig. 2).

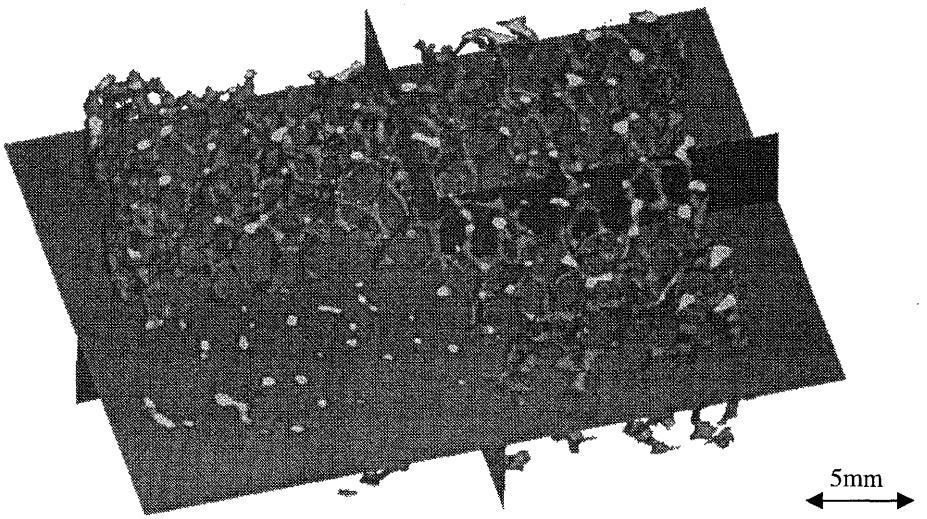



Fig. 2: 3D reconstruction of an open-cell aluminium foam (10ppi) based on 201 tomography cross sections realized by using the gradient shading method

The defined macroscopic and microscopic parameters are measured using the 2D-3D characterization routines within the digital image system. However the 3D routines orientation of cells and cell tracking presuppose the use of microtomography. These approaches deliver three dimensional information of the whole sample such as cell arrangement (homogeneity, gradient, orientation) as well as cell volume. Moreover, digital imaging with a microtomograph enables to analize the same sample for different levels of nominal compressive strain (cf. Fig. 5).

## 3 Analysis of parameters on open-cell foams

An example of characterization with the new combined 2D-3D analysis routine is given for open-cell aluminium foams (AlMg1SiCu) with 10 and 20 pores per inch (ppi) produced by investment casting. All samples were of dimension 25mm by 25mm by 25mm and were analized in the as-received and the compressed states. The maximum magnitude of the compressive strain was 75%. The characterization of the open-cell structures is performed with two digital imaging techniques (conventionally scanned and tomographic cross-sections) (cf. Fig. 1c & d). The porosity of the as-received 10ppi foam ranges at 95% and the one of the 20ppi foam at 93%.

The macroscopic structure of open-cell foams is characterized by the porosity, the distribution in cell size and cell arrangement aspects. The behaviour of porosity for different levels of nominal compressive strain (uniaxial compression stress-strain) is illustrated in Figure 3. For a nominal strain of more than 25% the porosity decrease rare in the middle of the sample. This behaviour corresponds to the one of regular honeycombs [2]. Peaks in the symmetrical course of curve (0% up to 50%) are caused by cells which shapes are more ellipsoid. After straining 75%, the sample has no symmetric behaviour because one side has totally collapsed. These discoveries are valid analogue for other cell sizes such as 20ppi and independent of the used digital imaging technique.

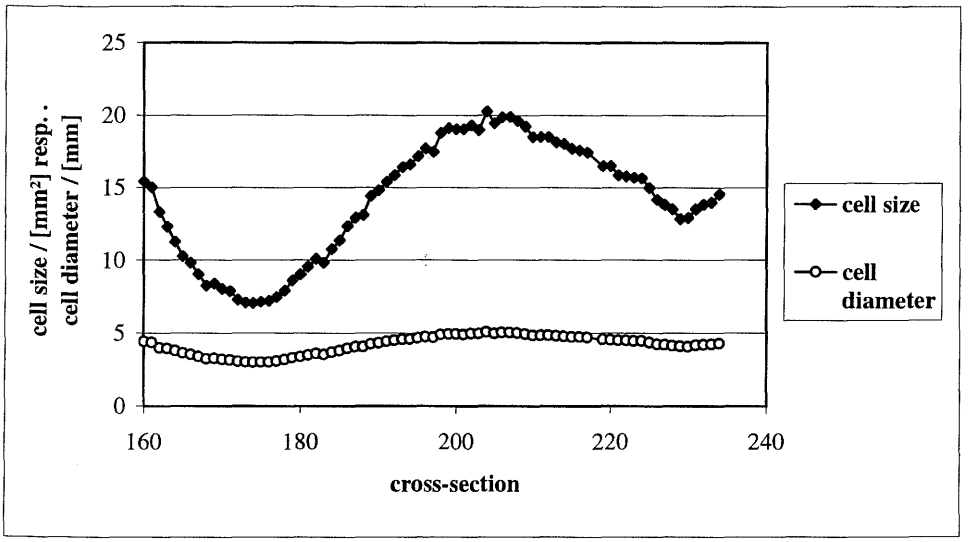
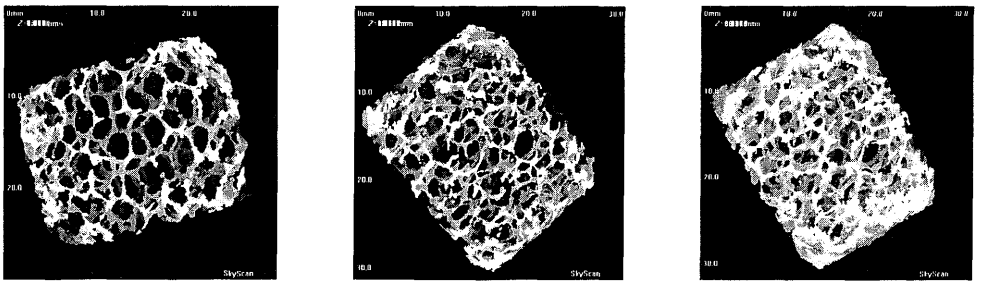



Fig. 3: The diagram shows the porosity in cross-sections of a 10ppi aluminium foam for different levels of nominal compressive strain (0% up to 75%). The middle of the sample is placed vertical to the direction of stress.

The cell arrangement is analized by use of tomography images. The three dimensional measurements are shown by means of a two dimensional distribution in grey values (Fig. 4). Each grey value of such an image corresponds to the frequency of metal in a voxel vertical to the analized cross-sections. The grey value distribution of a 75% compressed 10ppi aluminium foam shows the overlapping of plastic deformation and fractures of the cell structure (Fig. 5). Fractures can be detected on interrupted regions with same grey values in

the magnified image. Collapsed shares of the structure are detected in the middle of the cell wall as well as at cell nodes.
With such an two dimensional distribution in grey values it is possible to analize the homogeneity, gradients or anisotropic effects of the material.




(a) (b) (c)

Fig. 4: The images (a) to (c) show a distribution in grey values for 10ppi aluminium foam as-received (a), with 25% (b) and 50% (c) nominal compressive strain. The grey values correspond to the frequency of meta#l in a voxel with the height of the whole sample (black = no share of metal in the voxel).

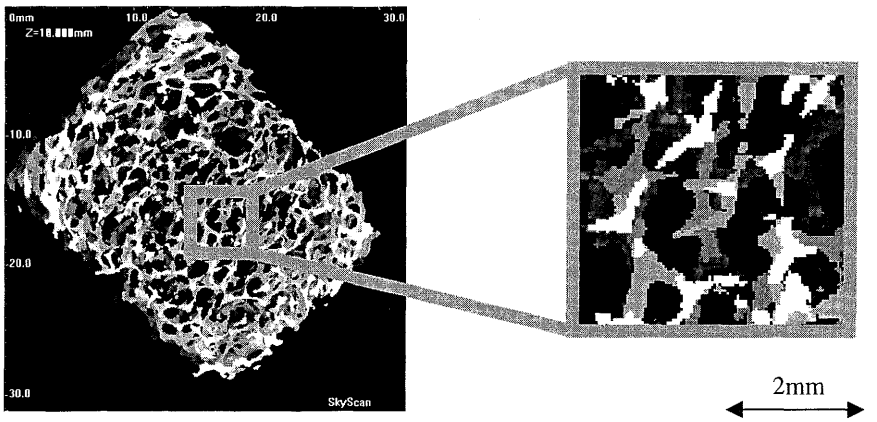



Fig. 5: The image on the left shows a grey value distribution for a 10ppi aluminium foam with 75% nominal compressive strain. The right image visualizes the magnified cell structure of the foam.

The analysis of the microscopic structure contains cell charateristics. For example the measurement of the cell volume is analized by the cell tracking routine. In this routine first an object fitting will be done by identification of cell fragments in the cross-section. Based on the centre of gravity of the fitted objects it is possible to track the cells exactly through the volume. The identification of one cell is obvious. The beginning, the middle and the end of one cell are clear defined by the minimal and maximal cell size (Fig. 6). The successive tomography cross-sections (distance: 60µm) are linked with each other and linear interpolated. In the case of the tested 10ppi aluminium foams the average cell volume is calculated with 44,24 $mm^3$.

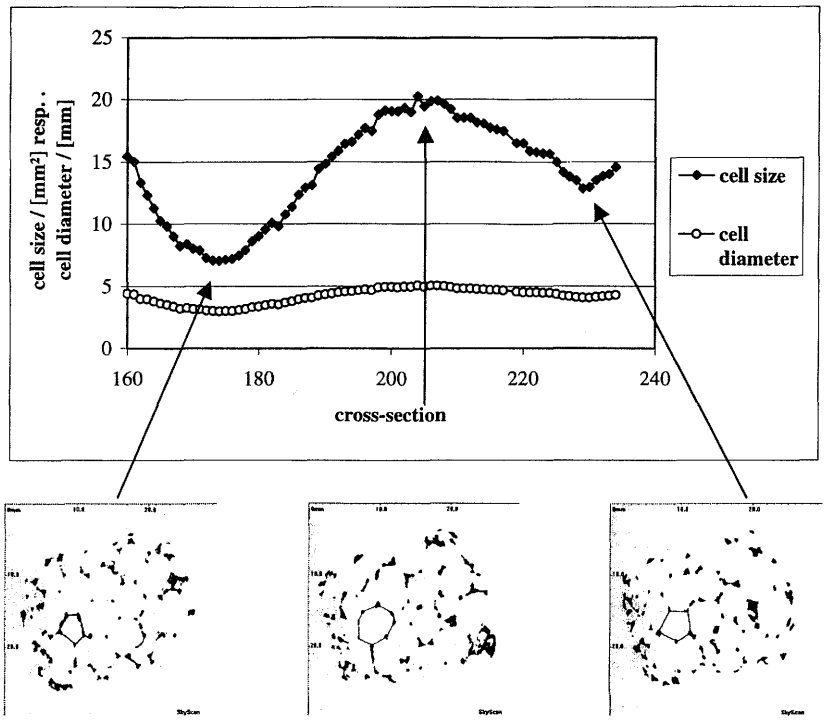



Fig. 6: Based on tomography cross-sections the volume of cells can be measured with the routines object fitting and cell tracking.

## 4 Summary

The use of microtomography with the possibilities of non-destructive imaging provides a potential alternative to the conventional preparation of cross sections. Opposite to the classic digital imaging techniques it saves time and work because there is no preparation to do. The new technique brings a fundamental change of cell structure characterization by delivering 3D data. Based on the 3D data it is possible to model and simulate the behaviour of real porous structures.

The enlarged analysis with the three dimensional routines cell tracking and cell arrangement takes a fundamental improvement of the characterization because the physical conditions of the structure can be considered. In addition to that the new 3D-parameters facilitates to reduce two dimensional parameters.

In future a detailed characterization of cell structures shall be a combination of the digital imaging techniques microtomography and scanning electron microscope. Based on the tomography the necessary macroscopic and microscopic parameters are measured. With the scanning electron microscope the material structure can be analized.

## References

[1] C. Klein, 3D LIVE No. 5 (1998), p. 72-73

[2] L.J. Gibson, M.F. Ashby, Cellular solids – structures and properties, Cambridge Press (1997)