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Analyzing the structure evolution of porous aluminum during cold rolling

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Abstract In times of increasing numbers of flights and growing airports close to residential areas, noise reduction of future airplanes is of major importance. To reduce the noise, which is dominating during landing, low-noise trailing edges of porous materials are investigated. A promising material is porous aluminum, which is produced using a salt infiltration method and available with various pore shapes and porosities. However, to meet the aeroacoustic and aerodynamic requirements ideally, adjustments of the pore shape and grade of porosity are necessary. This work investigates the possibilities to influence the porosity and pore shape of porous aluminum, using a cold rolling process. First results about the forming capability and evolution of porosity and pore morphology of porous aluminum during cold rolling are presented. For this porous aluminum was characterized for different degrees of deformation, using three-dimensional X-ray tomography.

1 Introduction

To protect residents of airports it is important to reduce the noise generated by airplanes during take off and landing. Whereas during take off the main part of the noise is generated by the jet engines, during landing the aerodynamic noise generated by flow around the airframe is dominating. This aerodynamic noise can be reduced using porous trailing edges (Herr 2007, Delfs et al. 2014). A promising material for low-noise trailing edge applications is a porous aluminum, which is produced using a salt infiltration technique and was received from “Exxentis”[1]. It also was found, that long pores that are oriented in the direction of flow are to be preferred, because bars perpendicular to the flow direction are generating noise (Herr et al. 2014). Therefore the performance of the porous aluminum as a material for low-noise trailing edges is expected to improve with elongated pores and an anisotropic porosity with a continuous transition from solid to porous material. To adjust the pore shape and porosity of the porous aluminum and create elongated pores a cold rolling process is proposed. It is expected, that the porosity will be decreasing with an increasing degree of deformation and that the pores will be elongating along with the material flow during the rolling process.

To investigate the forming capability and evolution of the porous structure, the porous aluminum was characterized for different degrees of deformation. For this the pore size, pore shape and porosity were analyzed using three-dimensional X-ray tomography and a line segmentation technique.

2 Material Characterization

For this work the porous aluminum PA 80-110 was chosen, due to its good noise reduction performance (Herr et al. 2014). A CT image of the material, as received from the manufacturer, can be found in Fig. 1a. The porosity of different types of porous aluminum was analyzed in a previous work (Lippitz et al. 2015). For this paper also the size and shape of the pores were analyzed. This is done using a line segmentation technique. As a first step image stacks in all three orientations parallel to the volume surfaces were extracted from the three-dimensional reconstruction. These images were then binarized to create black and white images. For the line segmentation analysis a lattice of parallel lines is

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superimposed to these images. Then the lattice is rotated 180° in steps of 1° and the length of the black and white segments is measured. As a last step the mean length for every angle can be plotted in structural ellipses (Rösler et al. 2010). For each orientation ten images were analyzed and the segment sizes were averaged to plot the structural ellipses.

Fig. 1b shows the pores that were detected in the sample. It can be seen, that most of the pores in this volume are connected, forming an open porosity. The pores of the porous aluminum as it was received from the manufacturer have an irregular shape. The structural ellipses for this sample, shown in Fig. 2a, have a circular shape indicating, that the pores in all three orientations do not have a preferred orientation.

3 Rolling experiments and structure development

For the rolling experiments a rolling mill with a maximum force of 600 kN, a roll diameter and width of 250 mm and a rolling speed of 416 mm/sec was used. The porous aluminium consists of the alloy AlSi7 and has an initial thickness of $h_0 = 10\,mm$. For each degree of deformation that was analysed, a new CT sample was cut from the rolled plate. The degree of deformation φ was calculated as follows:

$$\varphi = ln\frac{h_1}{h_0}$$

With the initial thickness h_0 and the final thickness h_1. The porosities for the different degrees of deformation are given in Table 1.

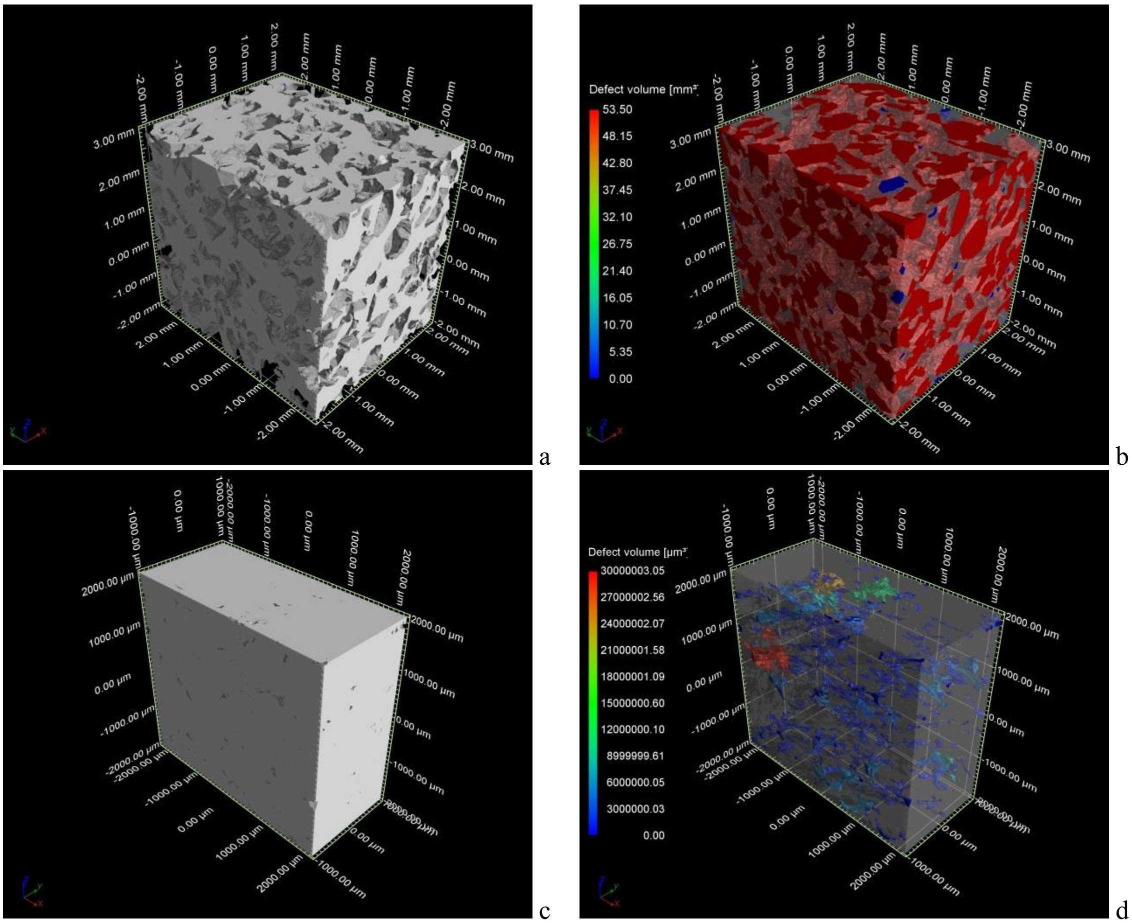

Fig 1 CT images of PA 80-110. **a** surface of the sample as received, **b** pores of the sample as received, **c** surface of the sample for $\boldsymbol{\varphi \approx -1,6}$, **d** pores of the sample for $\boldsymbol{\varphi \approx -1,6}$

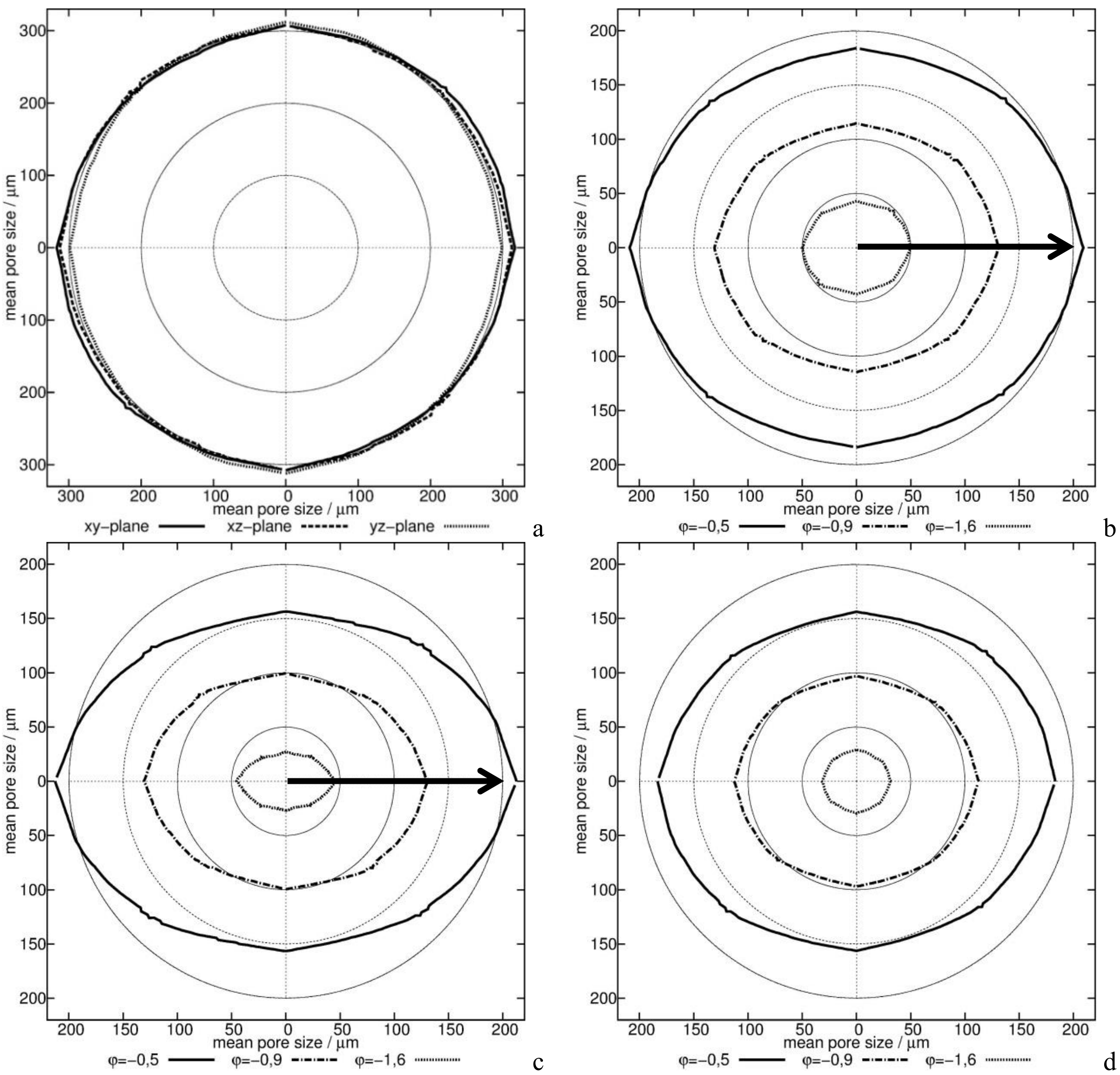

Fig 2 Structural ellipses. **a** as received, **b** planes parallel to the rolling direction (indicated by the arrow) and the rolled surface for selected degrees of deformation, **c** planes parallel to the rolling (indicated by the arrow) direction and perpendicular to the rolled surface, **d** planes perpendicular to the rolling direction and the rolled surface

Table 1 Porosity **Φ** for different degrees of deformation ***φ***

φ	As received	-0,2	-0,35	-0,5	-0,7	-0,9	-1,2	-1,6
ϕ / %	46	46	40	29	26	15	6	1

As can be seen from Table 1, the porosity is decreasing with an increasing degree of deformation. Up to $\varphi \approx -0{,}9$ most of the pores were connected and an open porosity was maintained. For a higher degree of deformation the connections between the pores were closing and mainly separated pores were observed (compare Fig. 1d). Note, that the porosity given for the porous aluminium "as received" is a mean porosity from different samples. Because the samples used for the CT scans are relatively small, the porosity for the rolled samples can differ from the mean porosity of bigger plates.

The structural ellipses for selected degrees of deformation are given in Fig. 2b-c. Fig. 2b shows the dimensions in planes parallel to the rolling direction and the rolled surface, whereas Fig. 2c shows the dimensions perpendicular to the rolled surface. The pore dimensions in planes perpendicular to the rolling direction and the rolled surface are shown in Fig. 2d. The rolling direction is indicated by the arrow. It can be observed, that the size of the pores is decreasing with an increasing degree of deformation. Also the pores are elongating in the direction of rolling. The effect of the decreasing pore size is intensified by the fact, that the line segmentation technique is applied to two-dimensional planes of the sample. The connections between the pores are small compared to the pore size. Therefore the probability to see two pores and their connection in one plane is decreasing with a decreasing pore volume. The pores appear to be isolated although they are connected. As a result the mean pore size that is measured by the line segmentation program is also decreasing. The elongation of the pores is strongest in the planes that are parallel to the direction of rolling and perpendicular to the rolled surface. The lengths of the pores in rolling direction that were measured in the planes parallel to the rolled surface and the planes perpendicular to the rolled surface are corresponding. The lower width in the planes perpendicular to the direction of rolling is a result of the compressive stress in the rolling gap. The smallest dimensions of the pores can be observed in the planes perpendicular to the rolling direction and to the rolled surface. Their length in these planes corresponds to the width in the planes parallel to the rolled surface, whereas their width corresponds to the width in the planes parallel to the direction of rolling and perpendicular to the rolled surface. In these planes the pores were compressed in the rolling gap, but were not elongated by the material flow.

4 Conclusions

Porous aluminum is a promising material for low noise trailing edges. For further improvement of the aeroacoustic characteristics, elongated pores and a continuous transition from solid to porous material are required. To adjust the porosity and pore morphology a cold rolling process was investigated. It was shown, that the porosity is decreasing with an increasing degree of deformation. Although the pores were finally closing it is possible to maintain an open porosity for high degrees of deformation. This is essential for aeroacoustic applications of porous materials. Furthermore it was observed, that the pores are elongating in the direction of rolling. Measurements of pore size and aspect ratio from two-dimensional images showed that their values depend on the orientation of the pores in the rolled plate.

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