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Influence of Extrusion Parameters on Microstructure and Texture of AlSi25Cu4Mg1

A. Pyzalla[1], J. Wegener[1], K.B. Müller[2] and K.-D. Liss[3]

[1] Strukturforschung, Hahn-Meitner-Institut Berlin GmbH,
Glienickerstr. 100, DE-14109 Berlin, Germany

[2] Forschungszentrum Strangpressen, TU Berlin, DE-13355 Berlin, Germany

[3] ESRF Grenoble, BP 220, FR-38043 Grenoble, France

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Abstract The influence of the extrusion temperature and the extrusion velocity on the microstructure, the texture and the residual stresses in the aluminum alloy AlSi25Cu4Mg1 after indirect extrusion is studied using microscopical methods as well as X-rays and high energy synchrotron X-rays. The results of the experiments indicate that the microstructure of AlSi25Cu4Mg1 is very stable with respect to high billet temperatures while the texture of the samples strongly depends on the billet temperature and the speed of the extrusion. The residual stress state in the bulk of the samples essentially is determined by the microstresses between the Al-matrix and the Si-particles while near the surface of the samples friction effects are visible.

1. Introduction

In manufacturing Al – alloy components hot extrusion processes are widely used. In those cases where the advantageous strength to weight ratio of advanced Al-alloys has to be combined with the increasing demands on wear resistance, interest focuses on extruded composites containing hard phases in the Al-alloy matrix. As hard phases Si-particles have the advantages of low weight and also of a low thermal expansion coefficient and thus they decrease the overall expansion coefficient of the composite. But, due to the thermal mismatch between the Al-matrix and the Si-particles residual microstresses evolve during deformation and cooling.

In order to enable a hot extrusion of these metal matrix composites with a high Si – content, new manufacturing routes have been developed /1, 2/. In the process used by /1/ first a billet is generated by spraying. The billet may be annealed and then is hot extruded.

The aim of the experiments described here is the determination of the influence of the extrusion temperature and the extrusion velocity on the microstructure, the texture and the residual stresses in hot extruded AlSi25Cu4Mg1.

2. Extrusion process

The extrusion trials were carried out on the 8 MN horizontal extrusion press at the Extrusion Research and Development Center of Technical University of Berlin.

Table 1: Extrusion Parameters

Billet Diameter	Container Diameter	Die Diameter	Extrusion Ratio	$T_{Billet} = T_{Container} = T_{Die}$ [°C]	Speed of Extrudates [mm/s]
105 mm	110 mm	35 mm	10:1	300	7.5, 15, 100, 150, 200
105 mm	110 mm	35 mm	10:1	400	15
105 mm	110 mm	35 mm	10:1	450	15

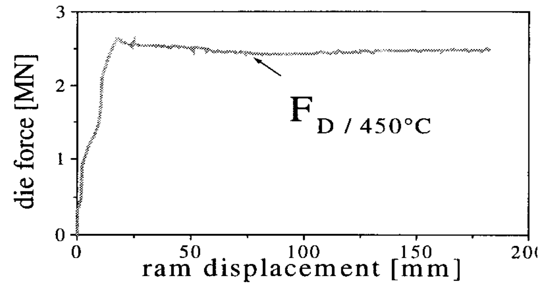

Figure 1 Die force versus ram displacement

For the measurement of axial forces the press employs load cells. By means of a computer aided measuring and evaluation system, the die force, the friction force and the total extrusion force can be determined in relation to the ram displacement /3/. The extrusion conditions are displayed in tab. 1. From former investigations with High – Silicon – Content – Al - Alloys /4-6/, high values of the hot deformation resistance for such kind of materials are known. In this case the high strength workability determined the choice of the extrusion method. Indirect extrusion of the above mentioned material was preferred.

The important advantage of indirect extrusion is the absence of friction between the billet and the container. This guarantees a largely homogeneous flow of the material and an important decrease of the required total extrusion force. In indirect extrusion the billet is stationary and the die is pressed towards the billet. The force required thus due to lack of friction force is lower than in case of direct extrusion. Here, the die force was registered versus the ram displacement during the hot extrusion process for billets with initial temperatures varying between 450° C and 300° C (fig.1). Higher extrusion temperatures lead to the formation of hot cracks. Obviously, the die force necessary decreases steeply with increasing temperature of the billets (fig. 2). Thus, due to the force required, extrusion at lower temperatures than 300°C were not possible here. With respect to the speed of the extrudates, extrusion trials were performed for billets with an initial temperature of 300°C, varying the speed of the extrudates between 7.5 mm/s and 200 mm/s. The die force necessary shows only a slight increase with increasing speed of the extrudates, which essentially can be linked to the lack of friction in the indirect extrusion process. Visual inspection of the samples after the extrusion revealed that in case of a high speed of the extrudates exceeding 150 mm/s the extrudates developed circumferential cracks.

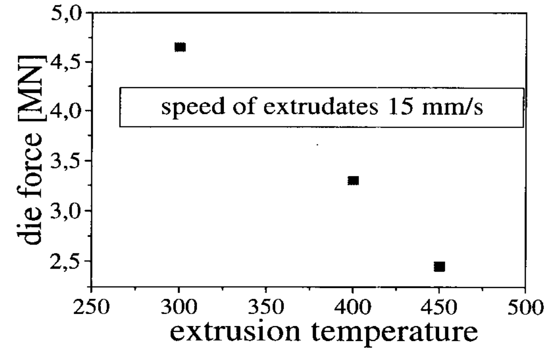

Figure 2: Die force vs. extrusion temperature

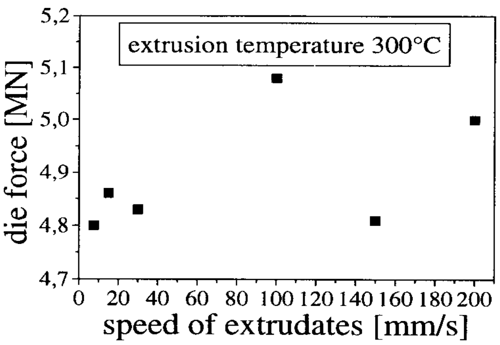

Figure 3: Die force vs. speed of extrudates

3. Microstructure of the extrudates

The microstructure of the extrudates was studied by optical, scanning and transmission electron microscopy. The microstructure after extrusion shows a homogeneous distribution of about 25 vol.-% fine Si-particles in the aluminum matrix (fig. 4). The diameter of the particles varies between 5 µm and 15 µm, approximately. Apart from the large Si-particles also in all extruded samples finer particles were present which were identified by EDX-analyses and color etching, respectively by their TEM diffraction pattern, as Mg_2Si and Al_2Cu.

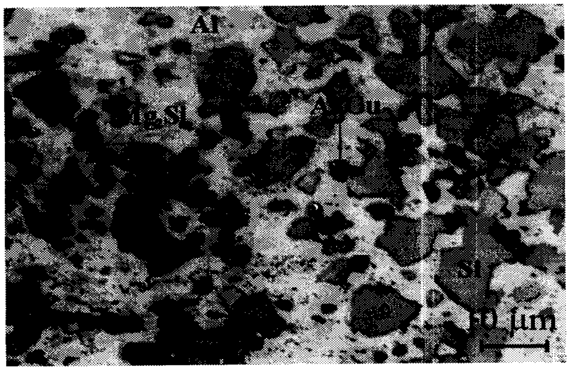

Figure 4: Optical micrograph of AlSi25Cu4Mg1 after hot extrusion at 300°C, speed 15 mm/s

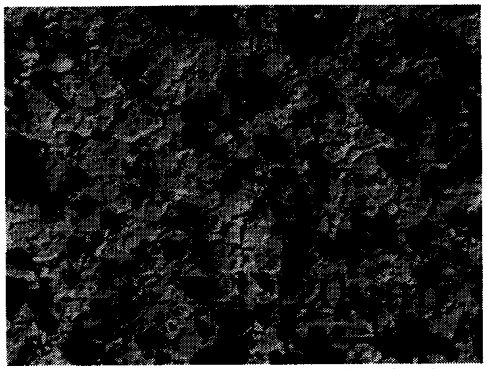

Figure 5: Grains in the Al-matrix after hot extrusion at 300°C, speed 15 mm/s

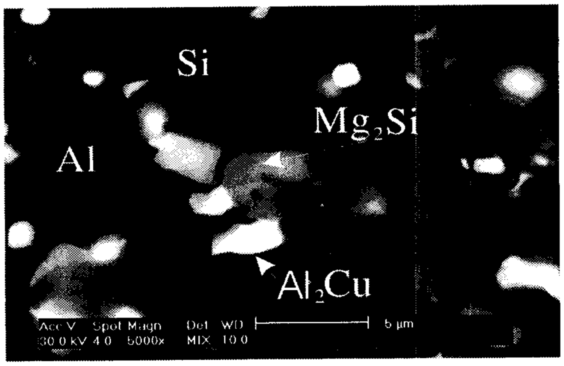

Figure 6: Scanning electron micrograph of AlSi25Cu4Mg1 after hot extrusion at 300°C, speed 15 mm/s

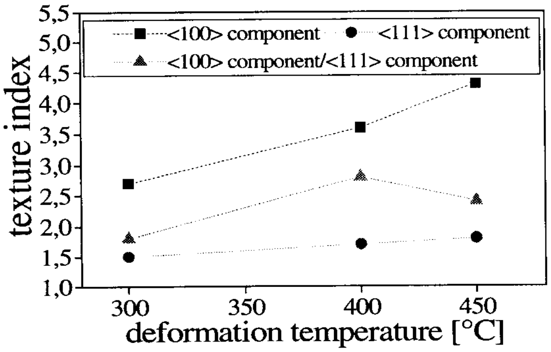

Figure 7: Dependence of the intensity of the fiber components on the deformation temperature

Optical microscopy (fig. 4, fig. 5)reveals no differences in the microstructure of the samples extruded at 300° C and those extruded at the highest extrusion temperature 450° C considered here. The same holds for scanning electron and transmission electron micrographs. The grain size of the Al-matrix (fig. 5) is approximately 4µm and does not differ significantly with respect to different billet temperatures. A comparison of the microstructure in transversal and longitudinal direction of the extrudates revealed that the grain elongation in extrusion direction is very small. These effects can be attributed to the high volume content of the alloy of Si- and intermetallic particles (fig. 6) which have a high hardness and alow deformability and therefore are obstacles with respect to the deformation of the Al-matrix.

Texture

Texture analyses were performed at cross sections of the extrudates using X-rays. The Si-particles due to their high strength and their globular shape as well as due to the high density of the billets (before hot extrusion) do not show any preferred orientation. In the center of the samples the aluminum matrix develops a <111> - <100> double – fiber - texture with a very weak <111> component.

With increasing billet temperature the <100> component increases in strength while the strength of the <111> fiber component appears to be rather independent of the deformation temperature (fig. 7). This fiber texture is different to findings of /7/ on single-phase aluminum alloys, which showed a dominant <111> - fiber component. With regard to the temperature dependence of the <100> - fiber, however, /7/ found a similar increase in strength of the <100> -fiber component with increasing temperature. By further substructure characterization /7/ concluded that this might be due to a higher recovery rate in the <100> fiber component. Regarding the speed of the extrudates the experimental data reveals that, while again the strength <111> - fiber does not depend on the extrusion condition, the strength of the <100> - fiber component and hence also the ration of the <100>/<111> fiber components increases with increasing extrusion velocity. This might be attributed to an increase of friction between the billet and the die which results in a higher temperature of those extrudates which were faster processed.

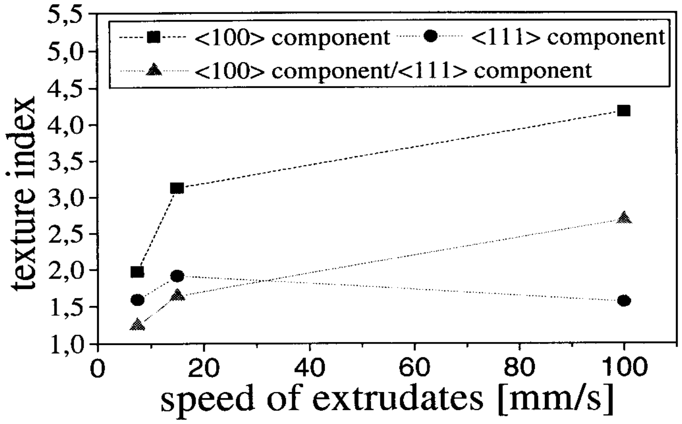

Figure 8: Dependence of the intensity of the fiber components on the speed of the extrudates

5. Residual Stresses

For residual stress analyses on the surface of the extrudates X-rays were used, while the residual stress state in the bulk of the samples was determined non-destructively by a recently developed method using high energy synchrotron radiation /8, 9/. The results of the experiments show (fig. 9) that the residual stress state in axial direction in the bulk of the sample is characterized by low residual macrostresses but high phase specific residual stresses. The macrostress state is typical for the residual stress distribution evolving due to temperature gradients during cooling but it also may result from the chosen extrusion ratio, since former investigations of the residual stresses in cold extruded steel revealed a similiar residual stress pattern in case of extrusion ratios larger than φ = 1,6 /10/. Due to the differences in the thermal expansion coefficient the residual stresses in the Al-matrix are tensile stresses of 100 MPa, approximately. The

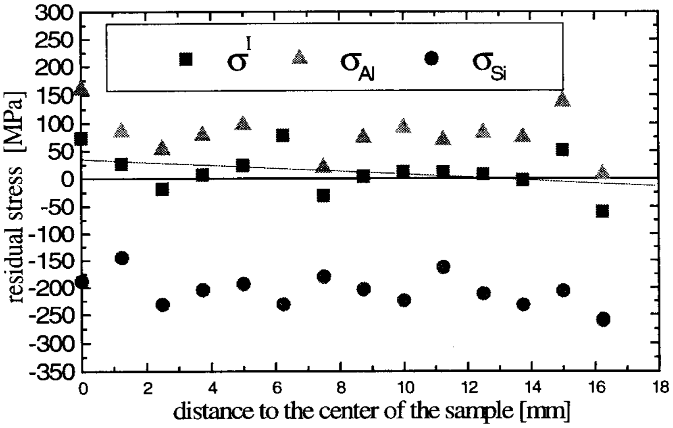

Figure 9: Phase specific residual stresses in axial direction in the sample extruded at 450°C, 15 mm/s

Si-particles contain the balancing compressive residual stresses of - 225 MPa approximately. A comparison of the residual stress values obtained in axial direction and hoop direction revealed that the residual stress state at all positions investigated across the sample diameter is nearly hydrostatic.

The residual stress distribution near the surface of the extrudates pressed at the conditions given in tab.1 at 450°C and 300°C is shown in fig. 10 and fig. 11. Similar to the results of the residual stress analyses in the bulk of the samples also near the surface the residual stresses in both phases are nearly hydrostatic, even within the penetration depth of the X-radiation of 30μm, approximately. Again in the Si – particles higher compressive stresses than in the Al-matrix are present. In a depth of more than 100μm even tensile residual stresses are determined in the Al-matrix. The residual stress distribution thus shows a surface effect directly at the surface, but, with increasing depth the residual stress level in both the Al-matrix and the Si-particles approaches the residual stress level determined in the bulk. The residual stress distribution near the surface of the samples extruded by 300°C and 400°C respectively 450°C does not show significant differences within the error margin of ± 40MPa.

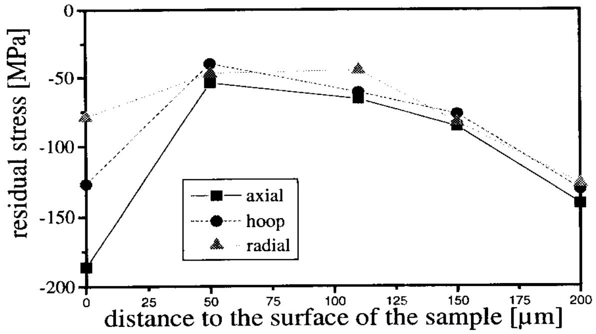

Figure 10: : Residual stress in Si-particles, conditions s.tab.1, billet temperature 450°C, speed 15 mm/s

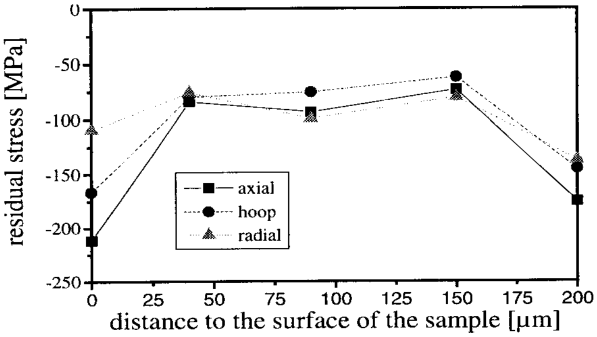

Figure 11: Residual stress in Si-particles, Billet temperature 300°C, speed 15 mm/s

6. Conclusions and Outlook

Analyses of the microstructure, the texture and the residual stresses in hot extruded AlSi25Cu4Mg1 reveal that the appearance of the microstructure in optical and scanning electron micrographs is stable under the extrusion conditions displayed in tab.1 up to an extrusion temperature of 450° C. Future investigations will concentrate on comparing also the precipitates and dislocation arrangement. Texture analyses showed a strong dependence of the strength of the components of the <111>-<100> double fiber texture on the extrusion temperature and the speed of the extrudates. Now tensile tests are performed at room temperature and at elevated temperature for assessing the influence of the different fiber texture on the formability of the extrusion products. The residual stress state analyses reveal that the residual stresses both in the Al-matrix and the Si - particles is nearly hydrostatic. Within the Si-particles the residual stresses are compressive, the Al-matrix contains tensile residual stresses. Due to friction effects there are small compressive macro residual stresses near the surface of the samples.

7 Acknowledgements

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