Key Engineering Materials Vol. 491 (2012) pp 137-144
Online available since 2011/Sep/27 at www.scientific.net
© (2012) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/KEM.491.137

Experimental and Numerical Investigations on Metal Flow during Direct Extrusion of EN AW-6082

M. Kammler [1, a], T. Hadifi [1, b], M. Nowak [2, c], A. Bouguecha [1, d]

[1] Leibniz Universität Hannover, Institute of Metal Forming and Metal-Forming Machines
An der Universität 2, 30823 Garbsen, Germany
[2] Leibniz Universität Hannover, Institute of Materials Science
An der Universität 2, 30823 Garbsen, Germany

[a] kammler@ifum.uni-hannover.de, [b] hadifi@ifum.uni-hannover.de,
[c] nowak@iw.uni-hannover.de, [d] bouguecha@ifum.uni-hannover.de

Keywords: Metal Flow, Direct Extrusion, Shear Zone, Visioplastic methods, Numerical Simulation

Abstract. In extrusion processes metal flow has an important influence on the microstructure and the mechanical properties of the extrudates. Thus, a deep knowledge about the metal flow during the forming process is required as basis for further computations of the microstructure evolution. In this study experimental and numerical investigations on the influence of friction on the metal flow in extrusion processes were carried out using visioplastic methods and finite element method (FEA). The objective was to determine the influence of ram speed, ram displacement and billet temperature on the material flow during extrusion of the aluminum alloy AlMgSi1 (EN AW-6082). For this purpose the forming stroke was varied at constant temperature so that a butt length of 100 mm and 150 mm could be produced. Further the influence of different ram speeds at 4.22 mm/s, 6.33 mm/s and 8.44 mm/s was investigated. In order to identify the metal flow and in special the shear zone as well as the dead metal zone, the billets of 250 mm length and a diameter of 140 mm were prepared with round aluminum indicator pins with a diameter of 4 mm which were placed in the plane of symmetry of the billet. For the experimental investigations a compact direct extrusion press with a nominal force of 10 MN (SMS Eumuco) was used. The numerical simulations were carried out using the commercial FEA system simufact.forming 8.1. After extrusion the billets were cut in the plane containing the indicator pins and the surface was polished and etched. The visioplastically determined flow lines and calculated strains were compared with computed flow lines in order to verify the results and to parameterize the simulation. Tresca’s friction model was used in the simulations to describe the frictional conditions between the billet and the tool components. The results of the experimentally and numerically determined strains of the billet at the container wall show a good similarity. With respect to the rigid modeling of the tool components and the fact that Tresca’s friction model considers relative speeds only indirectly the computed ram force curves show also quite good agreement with measured curves. However, the simulation results demonstrates that in further numerical studies advanced plastic flow criteria and flow rules should be used that take into account the anisotropy and inhomogeneity due to the changing grain size and microstructure of the workpiece material.

Introduction

In order to use the extrudates made from aluminum for application or further processing the mechanical properties and in particular the strength and remaining formability of the profiles are of great interest. These properties depend strongly on the local metal flow during the forming process and can be controlled either by the geometry of the tools or by global process parameters like initial temperatures or ram speed. Further more these have a great impact on the microstructure, in particular on the grain and subgrain structure and the precipitation distribution [1]. As the microstructure evolution depends on the forming history as well as on the temperature, in this context the typical shear zone in extrusion processes is of importance because its formation influences the metal flow in the primary forming zone as shown in Fig. 1.

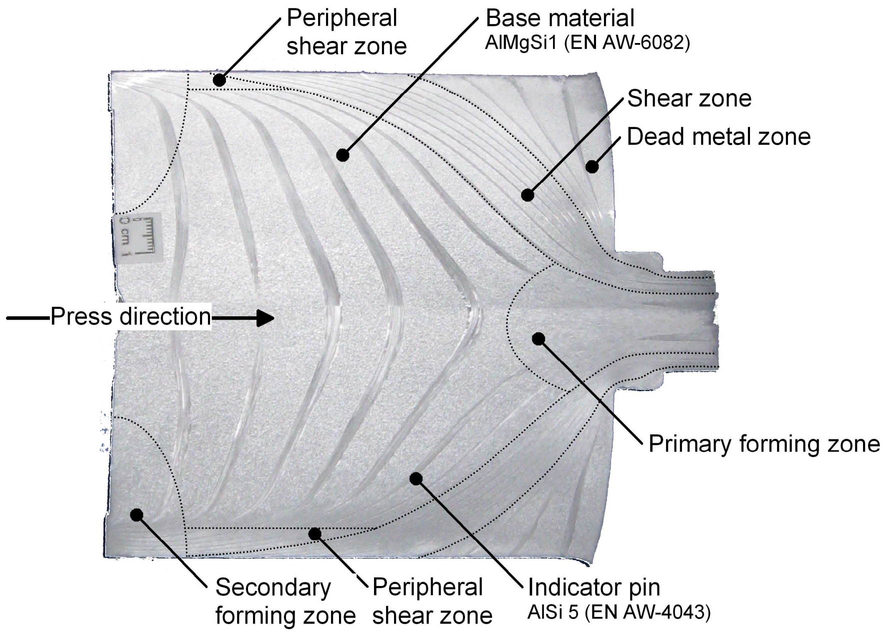

Figure 1: Overview of different zones in direct extrusion processes

To determine the microstructure evolution using the FEA many investigations were carried out [2, 3]. Often the Zener-Hollomon parameter is used for the prediction of the static recrystallization [4]. This parameter depends similar to the model according to Johnson-Mehl-Avrami-Kologorov (JMAK) for the numerical simulation of dynamic recrystallization basically on the equivalent plastic strain rate and the temperature [5]. Even in other physically based models as shown in [2] these state variables play an important role for the prediction of the microstructure of the workpiece. However it is remarkable that the simulation results of the microstructure in most cases show in general a good agreement with results from experimental investigations but in the areas of the shear zone and the dead metal zone they often deviate significantly from measurements as can be found for example in [4]. The rheological behavior is described by von Mises yield criterion and the frictional conditions are defined by Tresca's friction law. The aim of this study was to investigate the influence of ram speed, ram displacement and billet temperature on the material flow of the aluminum alloy AlMgSi1 (EN AW-6082). In order to identify the metal flow conditions in the different zones shown in Fig. 1 the billets were prepared similar to [6] and [8] with round indicator pins with a diameter of 4 mm made of AlSi5 (EN AW 4043).

Determination of Material Properties

The mechanical properties of the used material AlMgSi1 (EN AW-6082) are an important input for the numerical simulation of the extrusion process. The determination of the flow stress curves were carried out on a servo hydraulic testing machine (Instron VHS 400 kN) and the tested specimens with a diameter $d_0 = 11$ mm and a height $h_0 = 18$ mm were made from continuously casted material provided by Aleris International Inc., Bitterfeld. The flow curves were recorded at four different temperatures from $\vartheta = 400°C$ to $\vartheta = 550°C$ in steps of 50°C and at strain rates of $\dot{\varphi} = 1\ s^{-1}$, $\dot{\varphi} = 10\ s^{-1}$ and $\dot{\varphi} = 100\ s^{-1}$. To evaluate the results statistically for each of the twelve parameter combinations six tests were carried out.

In Fig. 2 the determined flow behaviour at varying temperature and strain rate is shown. As expected minor strain hardening effect at all temperatures and strain rates could be denoted. But it is remarkable that at high strains and high strain rates a softening effect of the material can be observed. Different explanations for this effect can be found in literature. Some authors ascribe the softening effect to the strain energy dissipation induced temperature rise. Others assume this to be due to alloy elements as they observed that strain rate sensitivity correlates with increasing alloy fraction [7].

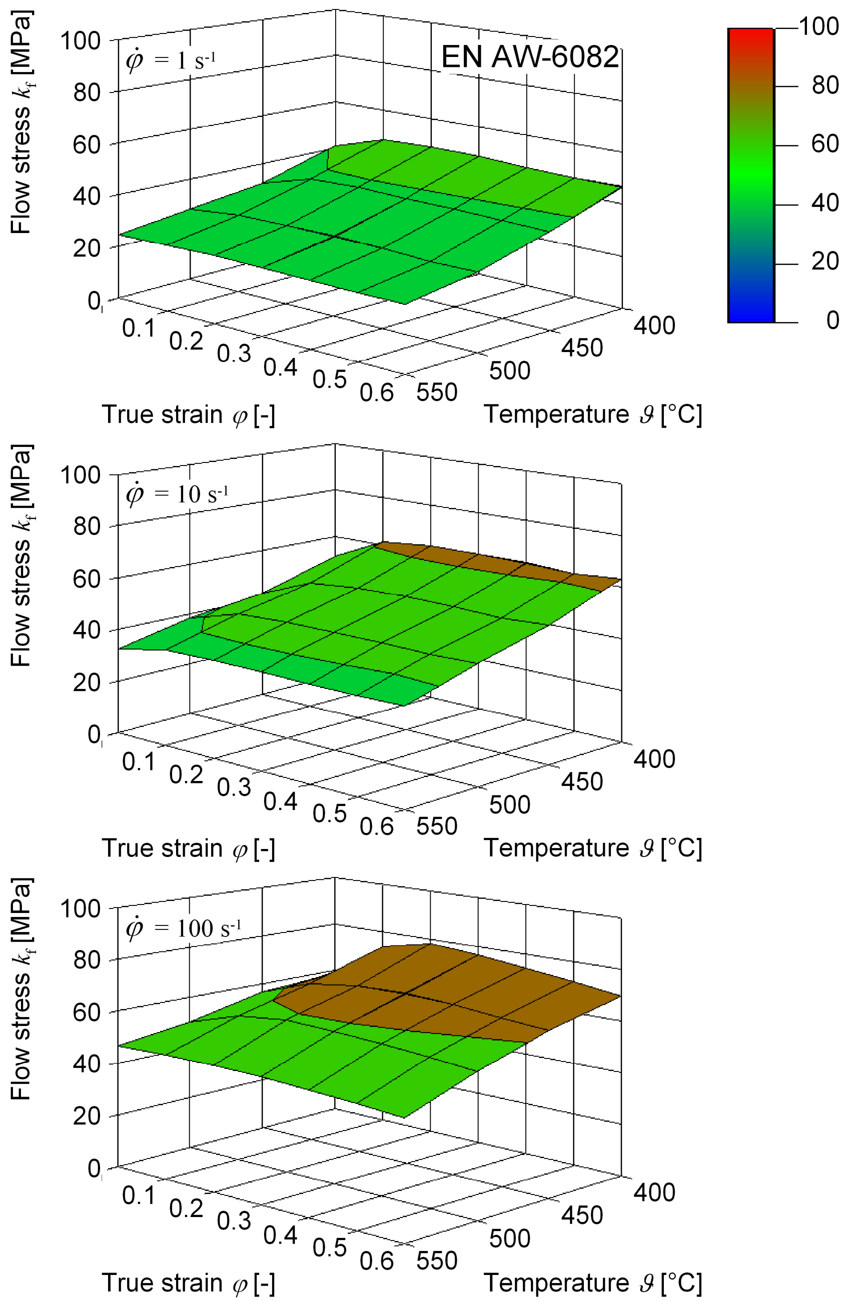

Figure 2: Flow curves for AlMgSi1 (EN AW-6082) in dependence of temperature, true strain and strain rate

Experimental and Numerical Investigations

The experimental investigations were carried out on a compact direct extrusion press with a nominal force of 10 MN (SMS Eumuco) at the Institute of Materials Science of the Leibniz Universität Hannover. As aforementioned the billets with a diameter of 140 mm and a length of 250 mm were prepared with round indicator pins [6]. To identify the metal flow in dependence of the ram displacement and ram speed, experiments at ram speeds of 4.22 mm/s, 6.33 mm/s and 8.44 mm/s were carried out. The billet temperatures were set to 490°C and 510°C while the ram displacement was set to 100 and 150 mm. The tools were heated up to 450°C. After extrusion the billets were cut in the plane of symmetry polished and etched with sodium hydroxide to get an adequate contrast between the workpiece and indicator pin material. With theses samples it is possible to measure the distance of the pins after extrusion and to determine the local strains according to (1) while the first pin was positioned in a distance of 12 mm from the die and the distance of the following pins was 14 mm.

$$\varphi_{zz} = \ln\left(\frac{l_1}{l_0}\right) \tag{1}$$

For the numerical investigations the commercial FEA system simufact.forming 8.1 was used to built up and compute a rotational-symmetric model of the process. The tools were modeled as rigid components while the plastic flow behavior of the billet material was defined by means of a piecewise linear approach with basis data determined from the material characterization. The initial billet temperature and the temperatures of the tools were set according to the experiments. For the description of the frictional behavior between the billet and the tools Tresca's friction model (2) was used and the friction factor m was varied until the axial strains at the container wall agreed with the measured values. The best results were achieved using a friction factor m = 1.0.

$$\tau = m \cdot k \tag{2}$$

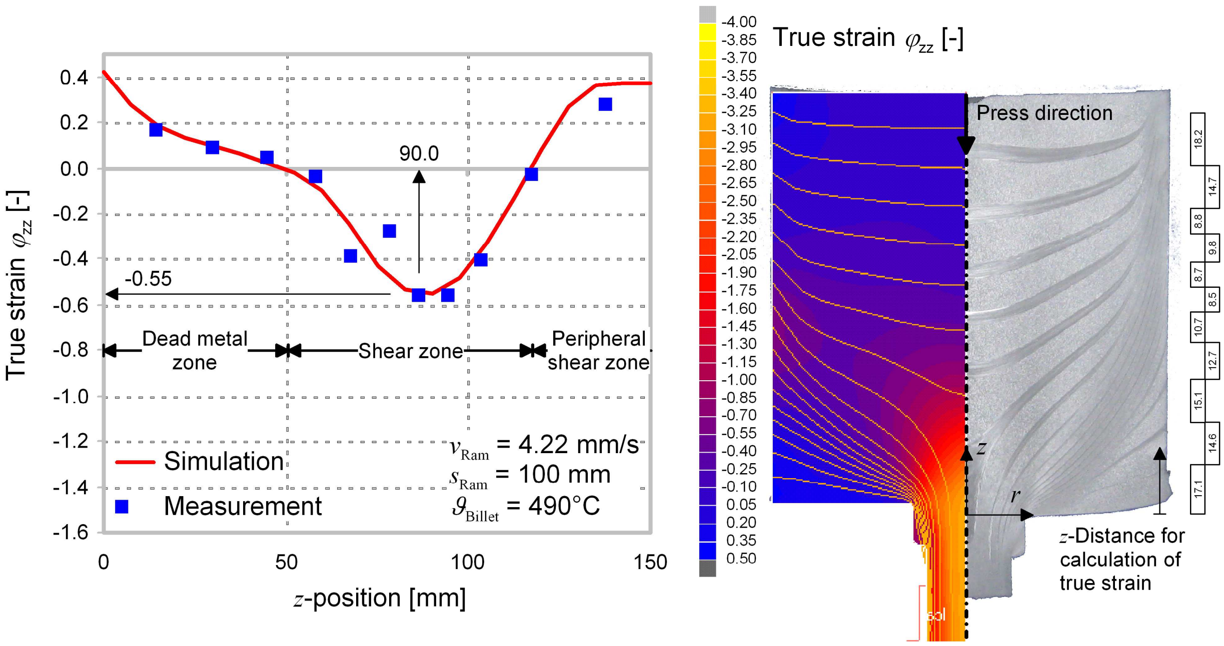

Figure 3: Experimental and numerical results for the axial strain at the container wall determined for a ram velocity v_{Ram} = 4.22 mm/s at ϑ_{Billet}= 490°C

The measured axial strains in the billet at the container wall were compared with the results of the numerical simulation as shown in Fig. 3, Fig. 4 and Fig. 5 at the end of the process with a ram displacement of s_{Ram} = 100 mm and s_{Ram} = 150 mm. The comparisons show that the usage of a friction factor m = 1.0 in the simulation is adequate to represent the friction conditions between the container wall and the billet for all tested ram velocities (v_{Ram} = 4.22 mm/s , v_{Ram} = 6.33 mm/s and v_{Ram} = 8.44 mm/s) as well as for both tested temperatures (ϑ = 490°C and ϑ = 510°C). In this investigation the primary objective was to calibrate the friction factor in the simulation to meet the measured strains at the container wall. Besides that it was possible to detect the position of the developing shear zone over the process time. The diagrams in Fig. 3 to Fig. 6 show the course of axial strains of the billet at the container wall starting at the die. While in the dead metal zone positive strain values are found (tensile strains) the sign changes to negative values (compression) in the following shear zone and after a minimum in the peripheral shear zone positive values are at hand. Although the position of the shear zone is constant at all three investigated ram speeds and both temperatures the magnitude of the minimum strain differs. The higher the ram speed and thus the strain rate the lower are the axial strains of the billet observed at the container wall as can be seen from Fig. 4. This characteristic was found in all experimental and numerical results and can be used to gain knowledge on the position of the shear zone in extrusion processes.

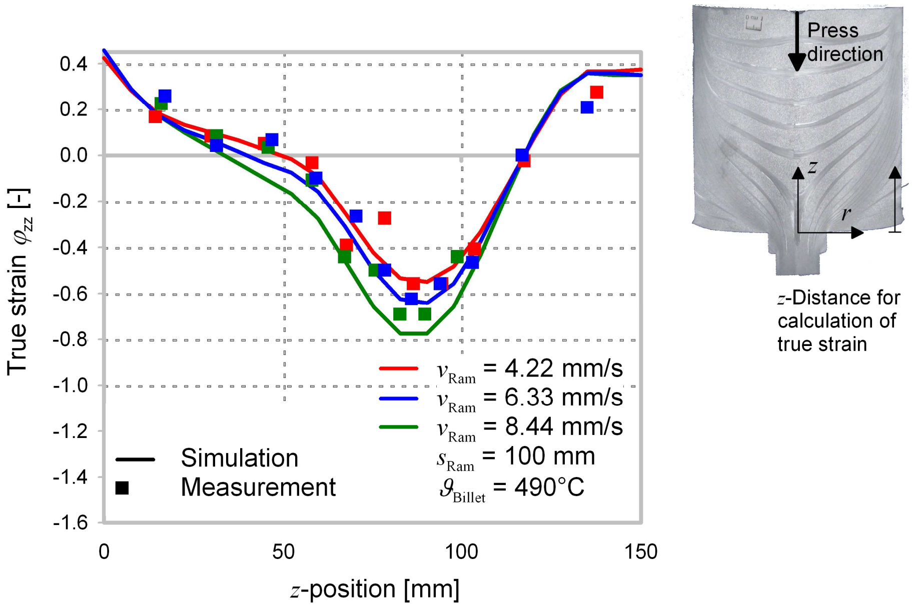

Figure 4: Experimental and numerical results for the axial strain at the container wall determined for different ram velocities at ϑ_{Billet}= 490°C

The results in Fig. 3 and Fig. 6 also show that the positions of the indicator pins and of the simulated flow lines differ especially around the center line of the billet while the agreement of measured and simulated axial strains at the container wall is good. It is assumed that the reason for this difference between the real and the simulated metal flow can be found in the description of the frictional conditions between the tool components and the billet and furthermore in the used flow criterion and the corresponding flow rule. Tresca's friction model describes the frictional shear stress as a fraction of the shear yield strength and neglecting any direct influences from the relative velocity. Since there are strong velocity gradients - even at the container wall as Fig. 7 shows - it can be valuable to use a velocity sensitive friction model for a more precise description of the frictional conditions between tools and billet in the process.

Regarding the grain structure of the billets depicted in Fig. 3 and Fig. 6 it is obvious that mainly in the shear zone a grain refinement during the process takes place that accounts for the formation of an anisotropic inhomogeneous microstructure. As a consequence it is questionable if the commonly used flow hypothesis and flow rule according to von Mises is suitable for the FE simulation of aluminum extrusion processes.

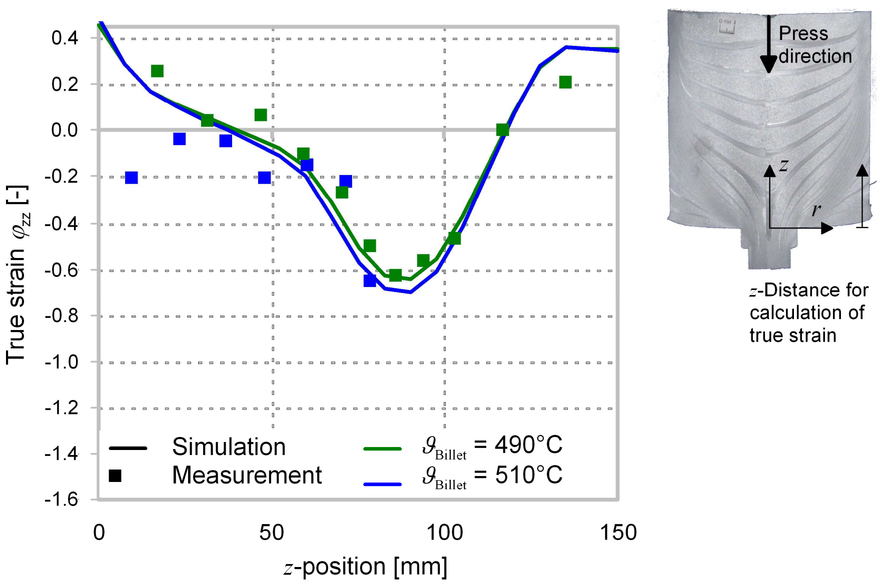

Figure 5: Experimental and numerical results for the axial strain at the container wall determined for billet temperature of 490°C and 510°C

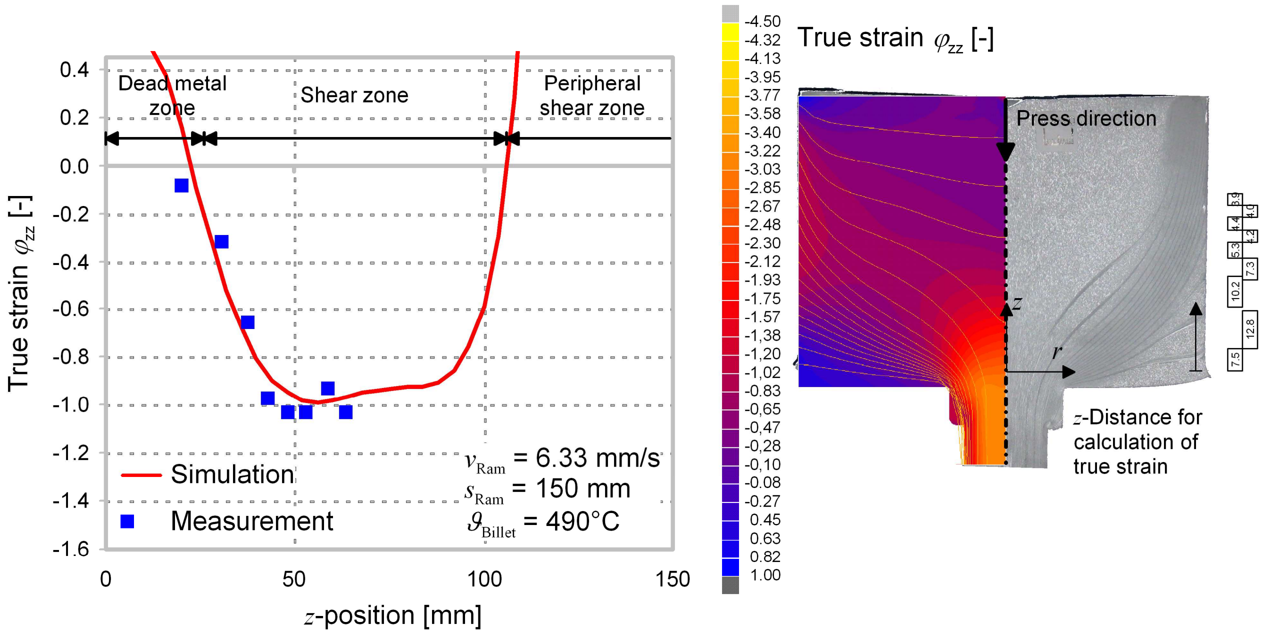

Figure 6: Experimental and numerical results for the axial strainat the container wall determined for a ram displacement of s_{Ram} = 150 mm

Therefore, it seems advisable to study the local microstructure evolution in extrusion of aluminum alloys with respect to local changes from isotropic to anisotropic material behavior in order to improve the description of the metal flow in numerical analysis. This assumption is supported by a comparison of measured and simulated ram forces for ram velocities of v = 4.22 m/s to v = 8.44 m/s. The graphs in Fig. 8 reveal a clear difference between experimental and numerical results while the courses of the forces over the ram displacement agree well. The offset of about 2 MN of the simulation results to the measured forces can be explained by the rigid modelling of the tool components. Disregarding of elastic deformations lead to an over estimation of the contact pressure and thus to higher forming forces. Further more it can be assumed that the plastic behavior in case of shear deformations is not described correctly by von Mises yield criterion.

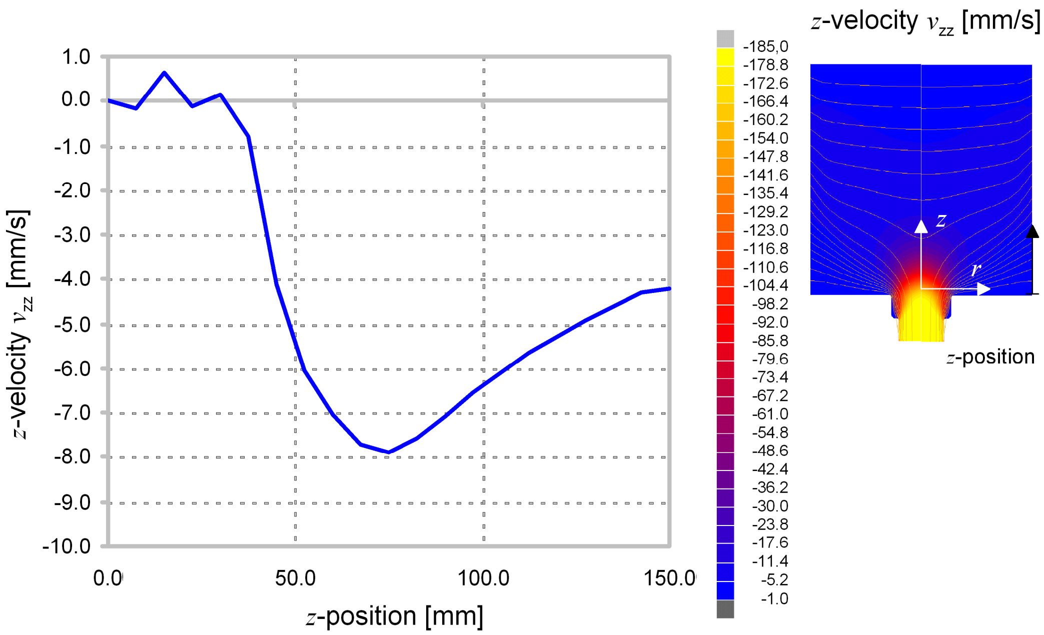

Figure 7: Simulation results of the velocity gradient at the container wall

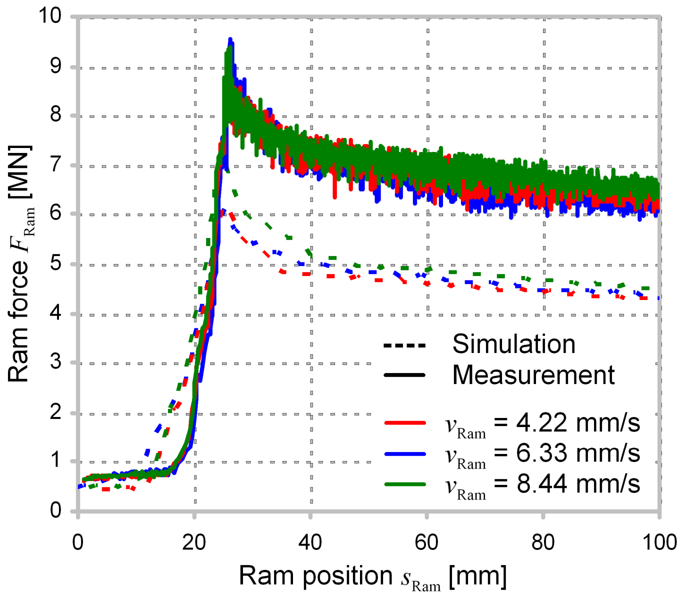

Figure 8: Experimental and numerical results for the ram force dependent on the ram position

Summary and Outlook

Since the microstructure development in forming processes of aluminum alloys is strongly influenced by the metal flow in this study, investigations on the dependency of the forming behavior on the ram velocity, the ram displacement and the billet temperature were carried out. It was found out that the use of Tresca's friction model using a friction factor of m = 1.0 is suitable for a close to reality simulation of axial strains occurring in the billet at the container wall. Moreover, the course of axial strains at the container wall enables the detection of the shear zone position which is typical for extrusion processes. The results also reveal that it seems advisable to investigate a possible improvement of FEA simulations using a velocity dependent friction model and to consider changes from isotropic to anisotropic material behavior in the numerical simulation of extrusion processes as shown in Fig. 9.

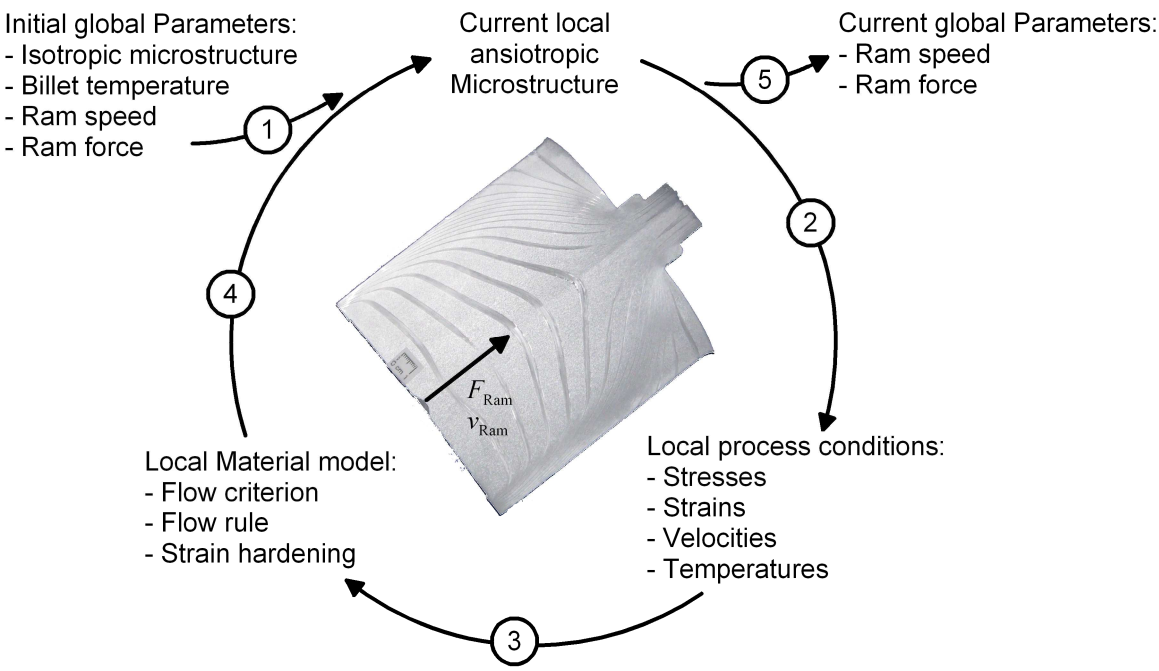

Figure 9: Concept for the consideration of microstructure changes in the numerical simulation of extrusion processes

Acknowledgment

The authors acknowledge the financial support of the German Research Foundation (DFG) for the research projects “Charakterisierung und Modellierung der Wechselwirkungen beim Strangpressen von Aluminium“ and “Untersuchung und Modellierung einer integrierten Spraykühlung beim Strangpressen mit simulationsbasierter Auslegung des Düsenfeldes“.

References

[1] W. Z. Misiolek, W. R. Van Geertruyden: Key Engineering Materials Vol. 424 (2010) pp 1-8, doi:10.4028/www.scientific.net/KEM.424.1

[2] F. Krumphals, P. Sherstnev, S. Mitsche, S. Randjelovic, C. Sommitsch: Key Engineering Materials Vol. 424 (2010) pp 27-34, doi:10.4028/www.scientific.net/KEM.424.27

[3] A. Foydl, N. Ben Khalifa, A. Brosius, A.E. Tekkaya: Key Engineering Materials Vol. 424 (2010) pp 35-41, doi:10.4028/www.scientific.net/KEM.424.35

[4] I. Flitta, T. Sheppard: Prediction of Substructure influencing static Recrystalisation using FEM Analysis; The 12th International ESAFORM Conference on Material Forming, 2009

[5] M.C. Weinberg, D.P. Birnie III, V.A. Shneidman: Journal of Non-Crystalline Solids Vol. 219 (1997), pp 89-99

[6] H. Valberg: Key Engineering Materials Vol. 367 (2008) pp 17-24, doi:10.4028/www.scientific.net/KEM.367.17

[7] F. Ostermann: Anwendungstechnologie Aluminium, Springer, 2007

[8] L. Donati, L. Tomesani, M. Schikorra, N.B. Khalifa, A.E. Tekkaya: Int. J. Surface Science and Engineering, Vol. 4, No. 1, 2010, pp 27-41

Progress in Extrusion Technology and Simulation of Light Metal Alloys
10.4028/www.scientific.net/KEM.491

Experimental and Numerical Investigations on Metal Flow during Direct Extrusion of EN AW-6082
10.4028/www.scientific.net/KEM.491.137

DOI References

[5] M.C. Weinberg, D.P. Birnie III, V.A. Shneidman: Journal of Non-Crystalline Solids Vol. 219 (1997), pp.89-99.
http://dx.doi.org/10.1016/S0022-3093(97)00261-5
[6] H. Valberg: Key Engineering Materials Vol. 367 (2008) pp.17-24, doi: 10. 4028/www. scientific. net/KEM. 367. 17.
doi:10.4028/www.scientific.net/KEM.367.17
[8] L. Donati, L. Tomesani, M. Schikorra, N.B. Khalifa, A.E. Tekkaya: Int. J. Surface Science and Engineering, Vol. 4, No. 1, 2010, pp.27-41.
doi:10.1504/IJSURFSE.2010.029627