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Characteristics of the Combined Rolling and Extrusion Process

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Abstract. The combination of the conventional forming processes rolling and extruding enables the continuous production of cross-sectional aluminum long products. Regarding power consumption and resulting material specifications, the combined process offers various advantages in comparison to its conventional alternatives [1, 2]. The combined rolling and extrusion process is in an early stage of maturity. The production of pure aluminum wire is state of the art. The material flow within the process can partially reproduced by the use of numerical simulations [3]. Some process specific characteristics need to be understood and controlled to obtain a better process design and to enable the future production of complex cross-sectional products.

This paper describes the results of experimental and numerical investigations regarding the combined rolling and extrusion process. The test specimen of a visioplastic examination on an industrial scale plant [3] was examined by the use of metallography. Those results where compared to a numerical simulation of the industrial experiment. The comparison of these results where then linked to some specific characteristics of the process. The existence of a dead zone with a shape comparable to the conventional indirect extrusion process was proved. The deformation zone of the combined process was divided into four zones which can be differentiated in the experimental as well as the numerical results. General design rules were derived from this differentiation. These design rules were used to optimize the forming geometry of an industrial scale plant. Axial forces where reduced and thus scrap material was minimized.

Introduction

Combined Rolling and Extrusion Process. In today's industry, the forming processes rolling and extrusion is widely used to manufacture aluminum long products. The combination of those processes offers numerous advantages in comparison to their single counterparts e.g. reduced investment costs, less space and energy consumption and reduced set-up times [4, 5].

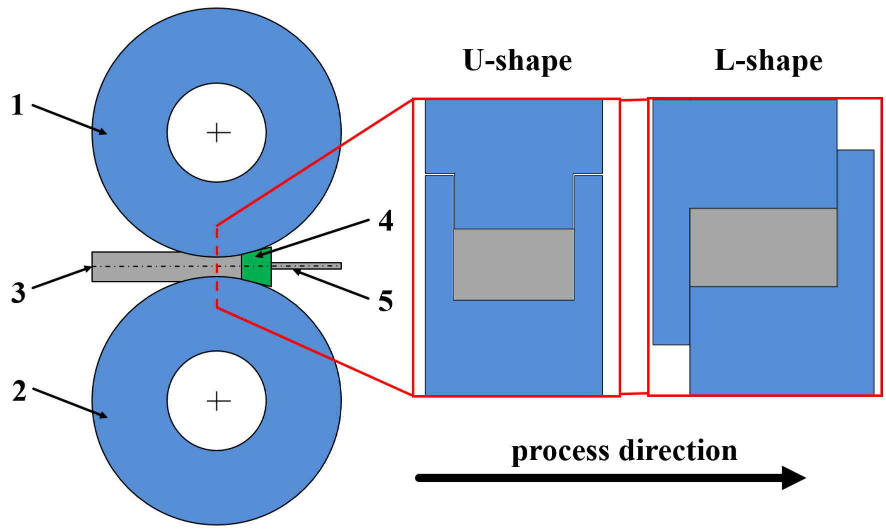

Figure 1: Schematic of the combined rolling and extrusion process and the two different roll designs

A schematic representation of the combined forming process is shown on the left side of Fig. 1. The rotating rolls (1, 2) are in contact with the workpiece (3). Due to the friction force between the workpiece and the rolls, the aluminum is processed through the hole of the die (4). The wire with the desired diameter (5) is produced.

The red framed cross sectional views of the roll gap between the rolls axis on the right side of the picture show the two different approaches for the design of the rolls. The advantage of the U-shape roll design is the compensation of the axial forces which will not go into the frame of the machine and cancel each other out. The disadvantage of this design is an uneven distribution of the necessary drive torque due to the different amount of contact area as well as no possibility of axial readjustment in connection with mechanical reworking due to wear. The L-shape roll design can be adjusted in the direction of the rolls axis and the distribution of the necessary drive torque is nearly even. The disadvantage is that the axial forces do not cancel each other out and must be handled by the mechanical construction.

Finite Elements Method. The approach of the Finite Elements Method (FEM) is the discretization of the workpiece in small (finite) elements and the incremental calculation of their deformation over time [6]. Using this approach, the simulation of forming processes and their global as well as location and time resolved resulting values (e.g. resulting geometry, forces, stresses) can be done. For the reduction of design time and costs, the use of this method is state of the art in the forming industry and scientific research [7, 8].

Proceeding and Discussion

Metallographic Examination. The test specimen of a visioplastic investigation of the material flow of the combined rolling and extrusion process [3] was subjected to a metallographic examination. The breakdown of the processed test material into individual test pieces can be seen in the illustrations given in Fig. 2. All subfigures show the same test material from different points of view. The direction the test material of Al 99,5 was processed is from left to right. In each of the three subfigures, a remaining part of the extruded wire can be seen.

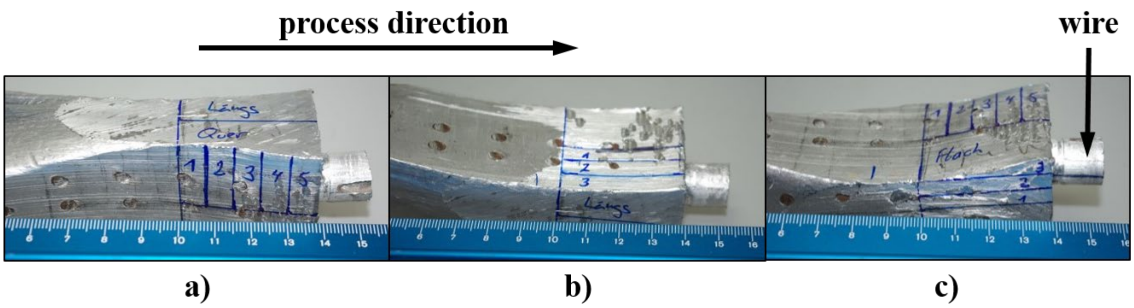

Figure 2: Sample markings of the sewing for the metallographic examination
a) cross-sectional view
b) longitudinal view
c) flat view

The cross-sectional test pieces (a) in Fig. 2) will be marked with Q1 to Q5. Their examination enable the investigation of the aluminums behavior in the view of the process direction. The longitudinal test pieces (b) in Fig. 2) will be marked with L1 to L3. They will show the behavior of the aluminum from the side view. The flat view test pieces (c) in Fig. 2 will be marked with F1 to F3. These specimens will give an insight of the material behavior from to the top view of the process.

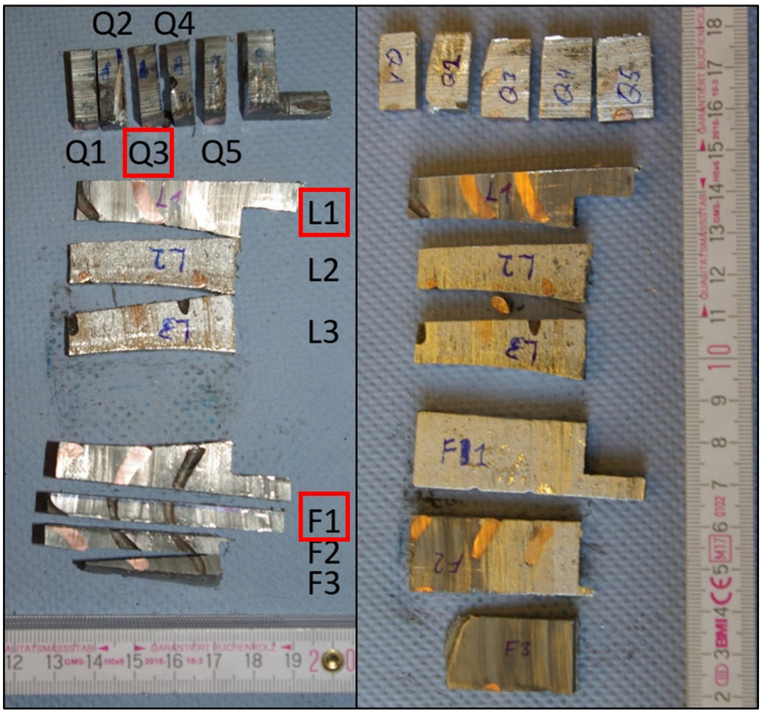

Figure 3: Sewed test pieces for the metallographic examination

In Fig. 3 the cut up test pieces are illustrated and titled as explained previously. After the cutting, the test pieces were embedded in holder material of Technovit 4017 and sanded with SiC-paper. The roughness of the sandpaper was gradually refined. The used sequence was 120 → 800 → 1200 → 2500 → 4000. The subsequent polishing was done by the use of a suspension of diamond and blue lubricant from Struers. The sequence of the diamonds particle size was: 6 µm → 3 µm → 1 µm. Afterwards a macro etching was carried out. Each test specimen was etched for three seconds with a suspension of 1 ml distilled water, 12 ml hydrochloric acid (40 %), 6 ml nitric acid and 1 ml hydrofluoric acid. The red marked test pieces in Fig. 3 will be shown in their prepared form for the further analysis of the characteristics of the combined process.

Figure 4: Microstructural preparation F1 of the test specimen

The first test specimen of the flat view (F1) regarding to Fig. 2 is shown in Fig. 4. The process direction is from left to right. In the upper right corner of the illustration, the position of the test piece is marked in red. The left edge is located in the roll gap. During the forming process, the right edge is in contact with the die. In the lower area of the right edge, the dies opening is visible. The upper edge is faced to the outside of the test material. It is in contact with the rolls. The lower edge is faced to the center of the test material. The preparation shows clearly differentiable lines pointing from the center of the test material to its outside. In the area of the roll gap (left), these lines are slightly more bend to the process direction on the outside of the prepared test piece. Moving into the process direction, this effect gets more dramatic. Approximately in the center of the test piece, the area of the lines oriented to the center of the workpiece start to accelerate. This acceleration increases towards the dies hole. In the conventional indirect extrusion process, U-shaped dead zones occur in front of the die [9]. A comparable characteristic of the lines can be seen in Fig. 4.

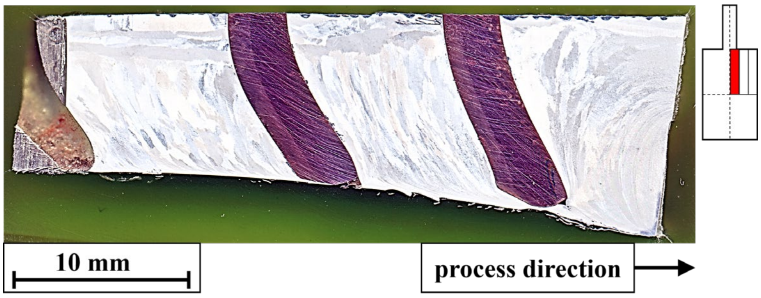

Figure 5: Microstructural preparation L1 of the test specimen

The first prepared longitudinal test piece (L1) is given in Fig. 5. The process direction is from left to right. The darker areas in the preparation are copper pins, inserted for a computertomographic examination of the material flow [3]. The left edge of the preparation is located in the roll gap of the combined rolling and extrusion process. The right edge is in front of the die. The dies opening is in the upper area of the edge. The lower edge is faced to the outside of the workpiece. It is in contact with the roll and for this reason shaped like it. The upper edge is located in the center of the workpiece. The prepared test piece shows clearly differentiable lines pointing from the outer edge to the center of the workpiece. At the outside, these lines are oriented more into the process direction in comparison to their center. After the last copper pin in front of the die, the center area of the lines accelerate and the U-shaped dead zone occurs in the same way it can be observed in Fig. 4.

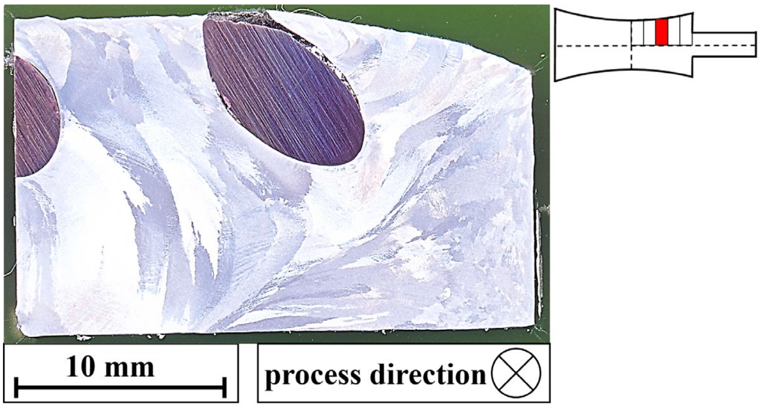

Figure 6: Microstructural preparation Q3 of the test specimen

The third prepared cross-sectional test piece (Q3) is given in Fig. 6. In this illustration of the test specimen, the point of view is oriented into the process direction. Again, the darker areas in the preparation are the copper pins. The left and the lower edge of the preparation is located in the workpiece center. The upper and the right edge are oriented to the outside of the workpiece. These edges are in contact with the workpiece. The straight shapes of the outer edges are interrupted and do not build a 90° angle as the shape of the rolls dictates. Consequently, there is no contact between the rolls and the workpiece. The test specimen Q3 proves that within the combined rolling and extrusion process, there is an area behind the roll gap where its forming chamber is not completely filled with the processed workpiece material.

Finite Elements Simulation. The industrial scale experiment used for the metallographic examination was simulated by the use of the FEM Software Simufact.Forming in Version 14. A fully coupled thermo-mechanical simulation was carried out. The workpiece was meshed with approx. 16000 hexaeder-elements. The boundary conditions were set as close as possible to the industrial experiment. The workpiece temperature was set to 440°C, the temperature of the rolls and the die to 150°C. Sticking conditions were assumed between the workpiece and the rolls. A friction free contact interaction was modelled between the workpiece and the die. A wire with a diameter of 15 mm was processed out of a cross-section of the cast bar of approx. 1200 mm².

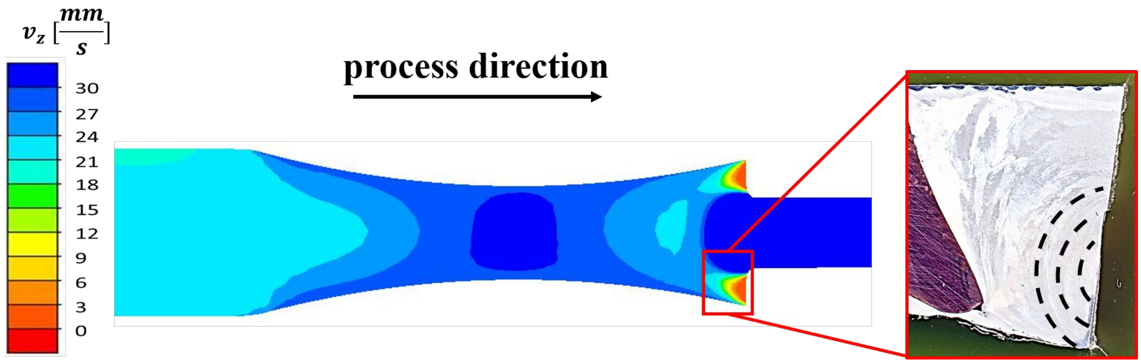

Figure 7: longitudinal cross sectional side view in the center of the simulated velocity in the process direction

In Fig. 7, a longitudinal centered cross sectional view of the simulated material speed in process direction is given. The process direction is from left to right. At the beginning of the forming process, the material which is in contact with the rolls moves faster into the process direction then the center of the workpiece. Anywhere in front of the roll gap the workpiece center accelerates that much, that it becomes faster than the outside of the workpiece. Behind the roll gap, the center of the workpiece reduces its velocity again and becomes slower than the outside. In front of the dies surface, above and below the dies hole, the velocity of the material in the process direction decreases to zero. The simulated shape of this dead zone corresponds to the results of the microstructural analysis and can be compared to the shape of the dead zone in the conventional indirect extrusion process. The substract of Fig. 5 which can be seen in the red box on the right side of Fig. 7 illustrates the good agreement between the experimental and the numerical results.

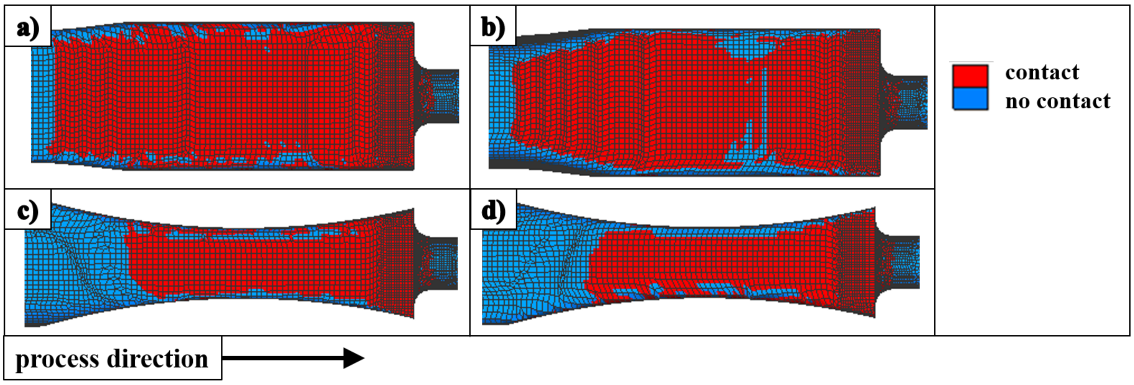

Figure 8: Contact situation between the workpiece and the rolls during the simulation
a) top view, b) bottom view
c) side-view (right), d) side-view (left)

In Fig. 8 the contact situation between the rolls and the workpiece is given from four diferent perspectives. The process direction is from left to right. The red marked elements are in contact with the rolls which are not visible in the pictures. The blue colored elements do not have contact to the rolls. The comparison of the top (a) and bottom (b) view with both side views (c, d) shows that the vertical surfaces of the workpiece get later in contact with the rolls than the horizontal contact areas. In front of the roll gap, the rolls and the workpiece are nearly in full contact. The elements on the edges might miss the contact due to the way of their discretization and the way the contact interaction is modelled in the simulation. Behind the roll gap occurs an area where the bottom of the workpiece (b) loses contact to the roll. This simulated behavior is in good agreement to the experimental results of Fig. 6. Moving in process direction, the workpiece gets in again in full contact with the rolls.

Results

Different areas of deformation. The microstructural examination of the test material and the results of the corresponding simulation are in good agreement. They are used to differentiate the forming chamber of the combined rolling and extrusion process in four zones. Fig. 9 illustrates these forming zones in a schematic representation. The process direction is from left to right.

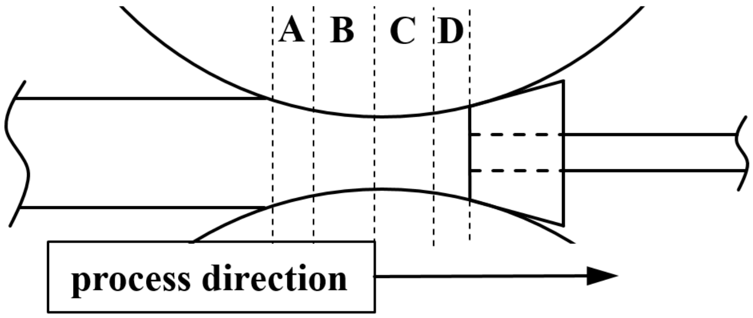

Figure 9: areas of deformation in the combined rolling and extrusion process
A: spreading zone
B: pressing zone
C: expanding zone
D: compression zone

The spreading zone (A) is the result of the different cross-sectional areas of the casted aluminum bar and the cross-section area of the rolling caliber at the beginning of the process. The cross-sectional area of the rolling caliber is bigger than this of the entering workpiece. The spreading zone ends at the point where both cross-sectional areas are equal due to the reduction of the forming chambers height. The test specimen given in Fig. 2 as well as the simulated contact situation in Fig. 8 prove this fact. The pressing zone (B) starts with the end of the spreading zone end ends in the roll gap. This forming zone is fully filled with the material of the workpiece. The geometric relationships as well as the simulated contact situation prove this characteristic. The complete filling of this forming zone results in a hydrostatical pressure. This pressure leads to a high contact pressure between the rolls and the workpiece. This high contact pressure results in high loads on the system. The spreading zone (C) begins after the roll gap. The enlargement of the cross-sectional area of the rolling caliber is a describing characteristic of this forming zone. The design of the forming geometry in the experimental and the simulated examination led to a situation where the workpiece and the rolls are not in full contact anymore. The expanding zone ends with the beginning of the compression zone. The compression zone starts when the workpiece and the rolls are in full contact again. The full contact in this forming zone occurs because of the compression between the workpiece and the die. This compression is necessary for the extrusion of the material through the hole of the die. Due to the full filling of the compression zone, a hydrostatical pressure is a characteristic of this forming zone as it is for the pressure zone. Also in this zone it leads to a high contact pressure between the workpiece and the rolls and thereby to high loads on the system.

The resulting differentiation of the forming chamber of the combined rolling and extrusion process can be used to formulate rules that must be adhered in order to achieve defined results. For example for the reduction of the axial loads using the L-shaped rolls. The size of the pressing zone and the compression zone must be reduced in order to reduce the loads. This can be achieved by increasing the spreading area e.g. by increasing the width of the forming chamber. The not fully filled spreading area can be seen as a non-optimal forming area design. The contact surface between the rolls and the surface is necessary to extrude the material through the die. Loosing contact within the process is not in the spirit of the process approach. The minimization of the expanding zone is a goal in the design of the forming geometry. Reducing this area is connected with the risk of a not functioning forming process. The amount of contact area must be high enough to extrude the material. Solving this conflict of goals is one aim of designing the combined process.

Dead zone. The experimental and the numerical examination prove the existence of a dead zone within the forming chamber of the combined rolling and extrusion process. This phenomenon can be compared with the dead zone in the indirect extrusion process. In the conventional indirect extrusion process occurs no friction between the billet and the press chamber. This is because of the non-existent relative movement between both contact partners. Compared to the combined rolling and extrusion process relative movement between the rolls and the workpiece occurs. The amount of this movement is small. Therefore the shape of the dead zone looks more like the shape of the indirect extrusion than the shape of the conventional direct extrusion processes dead zone.

Industrial Application

At the time this paper is written, an industrial scale combined rolling and extrusion plant is in the hot commissioning phase. This plant is the first one with the described L-shaped rolls. During the tests, elastic deformation of the rolls occur because of the axial forces in the forming chamber. This lead to scrap aluminum coming out of the forming chamber. The forming chambers geometry has been optimized in line with the obtained formulated design rules based on the defined process differentiation.

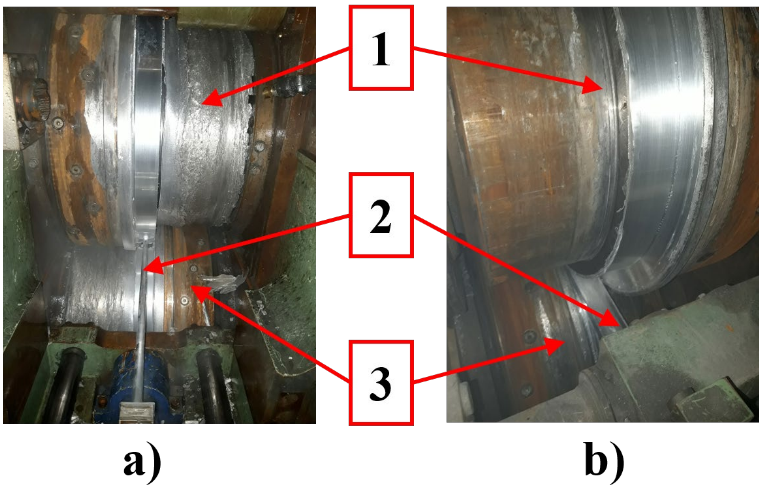

Figure 10: Adherent aluminum on the rolls of the combined rolling and extrusion process
a) old geometrical design of the forming chamber
b) optimized geometrical design of the forming chamber

The improvement of the optimization of the forming geometry based on the investigation results is shown in Fig. 10. On the left side of the picture (a) the upper roll (1) as well as the lower roll (2) are encased with scrap aluminum which left the forming chamber during the process. The die is pulled out of its working position and the wire (2) is visible. The right side of the picture (b) shows the improved forming geometry. The width of the forming chamber was significantly increased to expand the spreading zone and through this reducing the press zone. This results in a reduction of the axial forces and consequently in the load that needs to be handled by the system. The upper (1) and the lower (2) roll are not encased with scrap aluminum.

Conclusions

In this paper the test specimen of an experimental material flow investigation of the combined rolling and extrusion process was subjected to a microstructural analysis. The results of this analysis were compared to those of a corresponding numerical forming simulation. Both outcomes are in good agreement regarding the recognizable characteristics of the combined forming process. A dead zone comparable to the conventional indirect extrusion process has been occupied for the first time. The examination of the results led to a subdivision of the forming chamber in four clearly differentiable forming zones. This differentiation was used to formulate design rules for the forming geometry to obtain the reduction of the axial load. These design rules were applied to reduce the amount of aluminum leaving the forming chamber of an industrial scale combined rolling and extrusion plant. The application of the developed rules led to the expected results. The amount of aluminum leaving the forming chamber during the process was significantly reduced.

References

[1] R. E. Sokolov, S. B. Sidelnikov, Applications of Methods Combined Treatment for Obtaining Welding Wire from Silumins, Journal of Siberian Federal University 2015.

[2] U. Stahlberg, A. Göransson, Heavy Reductions by means of Extrolling: A theoretical Analysis including some Material Aspects, Journal of Mechanical Working Technology 1985.

[3] C. Heinzel, A. Salnikov, S. Müller, Experimental and Numerical Examinations Regarding the Material Flow of Combined Rolling Extrusion Process, The Minerals, Metals & Materials Society, Light Metals 2021.

[4] S. B. Sidelnikov, N. N. Dovzhenko, I. N. Dovzhenko, Modelling and Developing Processes of Integrated Aluminum and Aluminum Alloys Processing Abased on the Methods of Continuous Casting, Rolling and Extrusion, Siberian Federal University 2016.

[5] S. Dedov, Untersuchungen zur Entwicklung einer kombinierten Gieß-Umformtechnologie zur Herstellung hochwertiger Aluminium Bauteile, Universität Bergakademie Freiberg 2013.

[6] P. Fröhlich, FEM-Anwendungspraxis: Einstieg in die Finite Elemente Analyse, Springer, 2015.

[7] J. Mühlhausen, S. Gall, S. Müller, Simulation of the Co-Extrusion of hybrid Mg/Al Profiles, Key Engineering Materials 2010, pp. 113-119

[8] I. Alfaro, F. Gagliardi, E. Cueto, L. Filice, F. Chinesta, Simulation of Porthole Die Extrusion Process comparing NEM and FEM modelling, Key Engineering Materials 2010, pp. 97-104

[9] S. Müller, Weiterentwicklung des Strangpressens von AZ Magnesiumlegierungen im Hinblick auf eine Optimierung der Mikrostruktur, des Gefüges und der mechanischen Eigenschaften, Dissertation Technische Universität Berlin, 2007.