Latest Advances in Extrusion Technology and Simulation and 4th Extrusion Benchmark

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edited by
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Preface

This conference proceedings “Latest Advances in Extrusion Technology and Simulation in Europe and 4th Extrusion Benchmark” contains accepted abstract, full industrial papers and benchmark results from the 2011 edition of the International Conference on Extrusion and Benchmark (ICEB 2011) held in Bologna on 3-5 October 2011.

ICEB is a two-in-one event, merging a conference on the “Latest Advances in Extrusion Technology and Simulation” with an industrial worldwide contest: the “FEM codes Benchmark”. There is a a the strong connection existing between the industrial research and the development of affordable and robust process simulation: no step forward in extrusion technology is possible without a good simulation environment. For this reason these two key aspects are put together in ICEB, which for this reason has become the biggest event in Europe in this field.

Thus, ICEB provides, as first, conference sessions collecting invited keynotes, contributions from academia and industries, new techniques for design, optimization and management, new processes and new products. All the issues were divided in the following categories: Innovative processes, Material flow, Seam welding phenomena, Die design strategies, Process optimization, Process Management, Friction evaluation, FEM optimization and microstructure prediction.

Within the conference, the benchmark session represents the distinctive feature of the ICEB: it exploits FEM code capabilities and users’ knowledge in the simulation of an industrial extrusion process as it was designed and experimentally realized by ICEB organizers. Participants are asked to simulate this case only on the base of process input parameters, the results being undisclosed to them until the very last day, when they are already published and open to everybody.

In this edition, two identical hollow profiles of variable thicknesses, two different welding chambers and a critical tongue each, were extruded by a single die which performed the flow balance in two different ways: by means of feeders on the first profile and by means of bearings and pockets on the second one. The process was monitored in terms of process load, die thermal field, profile temperature, profiles velocity and die deflection, thus allowing a clear and reliable comparison with simulation results.

Due to the complexity of this matter, the benchmark should not be considered as a contest. Instead, it is an opportunity to detect, explore and discuss various issues about common simulation practice, with each participant having his/her own particular interest. We hope that these results will be useful for the improvement of the existing simulation skills as well as to contribute to the process optimization research.

There are many people to be acknowledged for their contribution to and assistance in publishing this volume. We would like to thank all the authors and co-authors of the papers and the members of the conference committees who contributed directly to the quality of the conference. We would also like to thank the numerous and generous sponsors for their financial assistance, which have made it possible to organize the ICEB and to carry out its expensive Benchmark.

Many thanks and gratitude to the conference co-organizers Professor A. E. Tekkaya, Dipl.-Ing Nooman Ben Khalifa for their precious assistance in raising the conference level, to the whole staff of IUL Department of Dortmund University and in particular to Dipl.-Inform. Alessandro Selvaggio and M. Sc. Ahmet Güzel for the great effort during the experimental trials. We would like also to thank Dr. Barbara Reggiani and Eng. Antonio Segatori from the University of Bologna for their continuous support in problem solving and conference organization.

We hope that these proceedings will become a source of valuable information useful in the everyday work for scientific and industrial researchers, engineers and students and we are pleased to welcome everyone to Bologna to the International Conference on Extrusion and Benchmark.

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Abstract
Extrusion Benchmark 2011:

Evaluation of different design strategies on process conditions, die deflection and seam weld quality in hollow profiles

Title of the Paper

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Abstract

Still today, the design of extrusion dies is mainly based on the experience and skill of the die makers. When a new profile has to be manufactured, some trials and prototypes are often necessary in order to achieve the optimal compromise between die productivity and die life. A more effective way is the use of simulations. Therefore there is an increasing demand for reliable simulations of the extrusion process, which has led to the organization of the biannual international conference "Extrusion Conference and Benchmark", specifically related to the optimization of FEM codes for extrusion analysis. In particular, the Extrusion Benchmark is a conference where the capabilities of different commercial codes are scrutinized in comparing the results with the data of an extrusion experiment. The event is realized in three main steps. In the first step, an experiment is designed and performed under strictly monitored conditions and repeated several times in order to provide a statistical significance of the monitored results. The second step is the process simulation, in which the organizers provide the information for carrying out the simulations. Then every interested participant (software houses, scientific and industrial users) performs the simulation prior to the conference. The third step is the comparison of the results. During the conference the hidden results of the experiment are disclosed and the different FEM codes predictions are compared to the experimental data, thus providing an interesting evaluation of the capabilities of the codes. It is important to note that, due to the complexity of the matter, it would be useless to consider the benchmark simply as a contest, which is instead, an opportunity to fix some points about the everyday simulation practice, each participant with her/his own particular interest. In this respect, the software houses can promote their code capabilities on the basis of scientific and well-monitored experimental data, the industrial users can verify their ability to properly perform a simulation with their own code or even select a code among those who are participating in the contest. In the 2007 edition of the extrusion benchmark, it has been shown that the FE simulation of the extrusion process is able to predict all main process parameters (press load, profile speed and temperature development) when different pocket shapes are used [1]. There, it was found that the simulation of the material flow, in particular by flat dies, can be very accurate, if proper thermal conditions are given.

On the other hand, the increasing complexity of the profile geometries, often of big size and small thickness, and the use of porthole dies with very slender mandrels (often multiple) and supporting legs determine the ever increasing importance of die deflection in determining the material flow. It is well known that a die can behave in a very different way from what is expected because of its deformation under process loads. In the scientific literature, investigations on the die deformation cannot be found explicitly. Only some approaches for measuring the pressure on the die face can be found [2,3]. In particular, investigations on the influence of the die deflection on the profile distortion, profile speed and temperature development at the die exit are completely missing. All these aspects, together with
the problem of die life was found to be the very first concern among extruders and die makers at the 2007 benchmark edition [4]. For this reason, in the 2009 edition, it was chosen to make clear if, and how much, a simulation code can properly manage this problem [5,6].

For 2011 benchmark, as suggested by 2009 ICEB participants, a hollow profile with seam weld generation, critical tongues and material flow balancing by means of feeders were developed. Two hollow profiles characterized by different thicknesses within the profile, two welding chambers and critical tongues (one fully supported and one partially supported) allowed the evaluation of the material flow balance, either by means of feeder size and position or by means of bearings. Accurate process parameters monitoring was carried out by using a self-calibrating pyrometer for profile temperature, six thermocouples for die thermal monitoring, a laser velocimeter for profile speed and two laser sensors for die deflection on critical tongues. AA6082 alloy was used as deforming material, while H-11 hot-work tool steel was selected as die material. The experiments were repeated at least three times under the same conditions in order to achieve a statistical distribution of the acquired data. These data are used as a reference for the 2011 edition of the extrusion benchmark.

**Fig. 1:** Dimensions of the Profiles (left) and bearing lengths (right)

**Fig. 2:** Porthole shapes and thermocouple position
References


High Strength Aluminium Alloys Extrusions - a Review of the Thermo-Mechanical-Process in High Performance Profile Manufacturing

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Abstract

High strength aluminium alloys extrusions have successfully been applied for years in transportation industry. High strength alloys are normally understood to be alloys based on the Al+Mg-Zn system (7xxx) with addition of Cu in some cases and of cause some micro structural controlling elements as Cr or Zr as examples. The level of strength in the hardened condition (T6) is typical in the range from 320 to 500 MPa. The combination of strength and ductility of extrusions from the 7xxx series alloy gives several advantages in light weight construction and the demand for lighter cars this should be an alternative. When looking into the cold formability and the specific strength like the banana-graph medium high strength 7xxx alloys seems to have an even greater advantage in comparison with several other materials in the automotive sector. Crash management applications are highly interesting. However the cost driven regimes of today in automotive sector strongly push the focus to extrudability when dealing with profile based solutions. The run-out speed and requirement linked to surface or micro structure are the productivity limiting factors. In many applications hollow sections are favourable, but this gives even more focus on extrudability and especially the tooling. Life time of tools in hollow section extrusion is cost vice critical.

Figure 1: Extrudability of several 7xxx alloys extruded with a test tool, strength of profile versus speed.

Figure 1 shows the reduction of extrusion speed with increasing yield strength in T6 temper of the extruded profiles, and the consequence is higher extrusion cost when asking for increased strength. However applying a higher strength alloy the part itself most probably can be designed lighter and saving of material cost give an advantage. It should be possible to optimize the alloy selection with
respect to extrusion cost and product performance. This gives the medium high strength alloys a strong position in the transportation industry when weight reduction at a reasonable cost is the goal.

Alloy developments with strong focus on extrudability and mechanical properties have been done at Raufoss [1, 2] through many years in cooperation with SINTEF and NTNU, [3]. In terms of fundamental aspects the influence of the alloying elements have been established, hot formability as function of Zn, Mg and Cu. Figure 2 shows the possibilities within the Al-Mg-Zn system to reach high strength but also the balance with hot formability reduction especially with increased Mg content. Additional the effect of dispersoid forming elements like Cr and Zr have been investigated. Dispersoids play an important role in 7xxx alloy due the control with critical properties like stress corrosion and fracture toughness. The cold formability of profiles is also microstructure sensitive. Significant improvements in extrusion speed are realized when the ratio Zn/Mg is increasing this means that alloys with high Zn and low Mg like 7108 and 7003 are favourable. Zr is the most promising element with respect to control the recrystallization phenomena. The microstructure as a result of alloy composition, homogenizing and extrusion is a key issue when dealing with the 7xxx alloys and have to be considered when optimizing of processes are done. A fully understanding of the thermo-mechanical process route in profile based components manufacturing is concluded to be fundamental for high performance products.

![Figure 2: Alloy development dilemmas in the Al+Mg+Zn system.](image)

References:


Finite element modelling of the charge welds evolution in a porthole die

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Publication on: Scientific journal.

Abstract

The level of the quality of an extruded profiles can be different on the basis of its final application: if for aesthetical applications the surface aspect is dominant, while in more severe loaded conditions the mechanical proprieties of the profiles become critical. A common aspect of both types of applications is the lack of defects in the profile; in particular, three types of defects have to be avoided: contamination of billet skin, seam welds and charge welds transition [1]. With regards to the last type of defect to be detected it can be observed that, during continuous extrusion, a welds is generated between the old and the new billet and it is called “charge or transverse weld” (Fig. 1). Indeed, although the extrusion process is regarded as a continuous process, in practice billets are discretely loaded into the press. The charge weld is generated at high hydrostatic pressure, but differently from seam welds, it usually carries contamination of oxides, dust or lubricant as a consequence of the loading into the press. Therefore, charge welds have to be discarded from the final profile since responsible for lower mechanical proprieties. In industrial practice, the discarded zone is often determined by means of rule of thumb or, in more critical applications, by cost and time-consuming intensive microstructure investigations at the beginning and end of each extruded lots.

![Figure 1: Examples of charge welds in industrial extruded profiles.](image)

The main focus of this paper was to present in detail the numerical simulation performed by means of the Altair HyperXtrude FE code to predict the charge welds evolution for a multi-profiles die.

Experimental trials were performed on 4 L-shaped hollow profiles (Fig. 2). Four billets made of a AA6060 alloy were extruded one after the other during the experimental campaign.

![Figure 2: Die geometry used in the experimental investigation of the charge weld evolution.](image)
The FE code Altair HyperXrude® was used to simulate the evolution of the transverse welds in the investigated extruded profiles [2]. The Arbitrary Lagrangian Eulerian (ALE) approach is used to simulate the material flow by means of a transient analysis with moving boundaries, i.e. with the billet length decreasing with the ram stroke progress. This avoids the frequent mesh regeneration typical of a pure Lagrangian approach, with a sensible reduction of the computational time [3]. The effective flow stress of the AA6060 alloy was expressed by the Sellars-Tegart inverse sine hyperbolic model [4] to yield the steady-state effective deviatoric flow stress. The prediction of the charge welds evolution was performed by means of a transient analysis with moving boundaries. In this type of problem, the boundary conditions for the flow and heat transfer equations are treated as time-dependant and the position of the billet back and of the billet-container interface tracked during the simulation time.

The total simulation time was 132 hours. Figure 3 reports the experimental and numerical percentage of the new material as a function of the stop mark distance for both profiles. A very good agreement was found on the trend of profile filling by the new material. The discrepancy of 150 mm between the experimental and numerical curves could be explained with the upsetting of the billet that is not computed by the FE code. Minimal differences were observed between the charge weld evolution of the profiles A and B as computed by Altair HyperXrude®.

![Figure 3: Comparison of the experimental vs. numerical results for percentage of new material over the stop mark distance for profile A and B.](image)

By the numerical computation, the minimal profile length to be scrapped after the stop mark in order to guarantees the complete replacement of the billet, thus removing the charge weld, was 2100 mm against 2000 mm experimentally scrapped by rule of thumb. A good agreement was also observed between the experimental and numerical results in terms of profile exit velocity with a peak error at the steady state less than 3%: experimentally a value of 320 mm/s was monitored for profile A against 311 mm/s computed by the FE code. A similarly accordance was found for the profile exit temperature after the initial experimental thermal transient.

References

Surface quality prediction in aluminium extrusion

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Abstract

The surface quality of aluminium extrusion products can be hampered by undesired surface features like die lines and pickups. In particular the presence of pickups is considered as undesirable. Surface pickups appear as intermittent torn marks on the aluminium extrusion products, often terminated with a protruding lump rising above the surface up to hundreds of microns, see [1]. The area of importance for pickup formation is the bearing area of the extrusion die. On the bearing, a sticking zone and a slipping zone can be distinguished, see e.g. [2]. Sticking is considered to occur when the nominal friction stress exceeds the shear strength of the extrudate surface, otherwise slipping occurs between the extrudate and the bearing surface. The length of the sticking zone can be calculated based on the pressure distribution as well as the frictional behavior in the bearing area, see [3] [4]. Within the slipping zone, material from the extrudate can be transferred to the tool surface. A four stage formation mechanism has been proposed that involves transfer initiation, material transfer and lump growth, lump detachment and finally, deposition on the extrudate surface. The lump formation process is represented in Fig. 1.

![Image of proposed formation mechanism for surface defects](image)

Figure 1: Proposed formation mechanism for surface defects: (a) initiation stage; (b) growth stage; (c) detach stage; (d) deposition stage. Arrows at the bottom right corner indicate extrusion direction.

Based the formation mechanism depicted in Fig. 1, a model describing surface quality of aluminium extrusion products has been developed. The model calculates initiation, growth as well as detachment of the lumps on the bearing surface. Important input parameters in the model are the microgeometry of
the bearing, the constitutive behavior of the aluminium alloy, the pressure distribution in the bearing area resulting from the bearing geometry as well as process parameters of the extrusion process as exit speed and surface temperature of the extrudate close to the exit.

In order to validate the model, the size and number of pickups on the surface of a labscale extruded strip of AA6063 have been calculated. In these experiments, extrusion temperature, choking / relief angle, exit speed and bearing roughness has been varied. The results of the model have been compared to the experiments and show good agreement.

The calculation results of the model can be presented in terms of surface quality diagrams, where contour lines of the (normalized) calculated number of lumps are presented in terms of exit speed and extrudate surface temperature. These diagrams are unique for a certain combination of geometry of the extrudate and the aluminium alloy. An example of such a diagram is shown in Figure 2. Within this diagram it can be seen that at extrudate surface temperature of around 540 °C and exit speeds of 25 m/s results in the worst surface quality. In this case, both extruding at lower velocities and at higher velocities will result in a better surface quality in terms of pickups. These diagrams can be used to optimise process conditions with respect to surface quality within a certain process window.

References

Experimental investigation of process performance enhancing in extrusion of a magnesium hollow profile

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Abstract

Magnesium alloys are looked with great interest due to their combination of good mechanical properties and very low density. To date, the market of extruded magnesium profile is very small due to difficulties in the material deforming processes at acceptable process performance [1,2]. Therefore, enhancing of process performance in extrusion of a round hollow profile is presented in this paper. Despite it is often common practice to adopt die design similar to aluminum production for magnesium, a tailored design has been developed with the aim to increase process efficiency and die resistance.

The process was monitored under variable extrusion speed for two different alloys: ZM21 and AZ31. Process speeds were increased from the usual 0.2 mm/sec (1.4 m/min) to at least 1.5 mm/sec (10.4 m/min) for ZM21 and to 1 mm/sec (7 m/min) for AZ31.

Results of the trials are reported in terms of loads and surface quality of the extrudates, evidencing when burning of the material or pick-up occurred (Fig. 1). Finally a correlation between the profile surface and speed is proposed.

![Figure 1: Profiles in ZM21 after the extrusion with visible different coloring.](image)

References:


Influence of contact friction conditions on thin profile simulation accuracy in extrusion

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Abstract

The paper presents further development of the simulation program QForm-Extrusion for the needs of the aluminium industry [1]. The program has shown good accuracy in two recent benchmark tests simulations [2]. Meanwhile some cases of the most complex profiles with thin walls may have had slightly less accuracy in the results than are usually observed in our simulation practice and this has highlighted the necessity for more profound investigation. It has been found that the effect may be caused by specifics of friction conditions, inadequate finite element mesh density distribution or by the influence of the die elastic deformation. Experimental and theoretical studies show that the friction traction on the interface between the tool and deformed material can be represented as a combination of adhesive friction force and the force that is required to deform surface asperities. The adhesive friction component is caused by molecular links of different nature between the body surfaces and is dependent on the material’s physical properties. The deformation component is required to deform the asperities and depends on the roughness of the surfaces, flow stress of the deformed material, contact normal pressure and sliding velocity. At high contact pressure the deformation component is predominant while when the normal pressure is small the adhesive component is relatively more influential.

In aluminium extrusions we can clearly distinguish two different areas with respect to friction conditions. The first area covers the inner surface of the container, feeding channels and pockets (fig.1,a). Here the contact pressure is very high and the deformation friction factor is close to 1. Due to additional effect of the adhesive friction the total friction traction formally can be bigger than the shearing flow stress. This means that the metal sticks to the surface of the tooling set and sliding takes place inside the deformed material caused by intensive shearing deformation.

The second contact area is the bearing area that can be visible in the Bearing Editor of QForm-Extrusion program (fig. 1,b). In this area we can distinguish three zones with different friction models:

- The sticking zone with predominantly deformation friction. It is situated at the entrance to the bearing and may extend when the bearing has a choke angle.
- The sliding zone where deformation friction decreases.
- The zone where the material may separate from the die due to small normal contact stress.

Relative dimensions of these zones depend on several parameters and may vary along the profile perimeter depending on actual choke angle, thickness of the profile and velocity of the material flow in particular point.
Thus to get the precise results of the material flow we took into account the variation of the effective choke angle and the actual thickness of the profile. To get these values the material flow problem was coupled with the simulation of the tool deformation.

The presented method of friction realisation in our extrusion simulation program is quite universal and allows taking into account all the parameters of the friction phenomenon. It takes into consideration both the physical model of friction as well as the geometrical aspects caused by the die deformation. Now these parameters are calculated and the model works in full scale. The industrial verification has shown that the model provides accurate prediction of the material flow in extrusion of the complicated thin wall profiles which is sufficient for majority of practical applications.

References:


Aluminum Extrusion Simulation using Finite Element Method

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Abstract

It has been widely accepted that the finite element method (FEM) is a powerful numerical tool for the simulation of metal forming processes. For the extrusion process, many researchers in the past decade have made important contributions by using FEM to model the material flow during extrusion as well as the design of extrusion tooling. On the shop floor, however, the modeling of extrusion is not as popular as is the modeling of other metal forming processes. This is mainly due to the unique complexities associated with FEM-based extrusion simulations, such as long computing time, the singularity at sharp die corners, and meshing/remeshing issues.

As the computing and modeling technologies become more mature, the commercialization of FEM extrusion modeling to the shop floor environment gradually becomes feasible [1]. In this paper, an aluminum extrusion process, used to produce impact beams (Figure 1), is simulated for validation and demonstration of FEM-based process modeling.

DEFORM is a commercial FEM-based simulation software used to model manufacturing processes. Due to its proficiency in simulating large plastic deformation and microstructure evolution, DEFORM has been applied successfully to various metal forming processes, including open and closed die forging (hot, warm and cold), rolling, joining, heat treatment and machining. During most forming processes, the workpiece shape and tooling-workpiece contact conditions are constantly evolving. These transient characteristics are accurately captured by the Updated Lagangian (UL) method, as shown in Figure 2 from the impact beam extrusion simulation. Due to the localized deformation at the die orifice, the finite elements degenerate almost every step. Fine mesh is required not only to produce a better solution field in high extrusion ratio areas, but also to sufficiently represent the complex cross-sectional profile. The required CPU time using UL for aluminum extrusion with a high extrusion ratio can be extensive, though it is heavily dependent upon the complexity of the extruded geometry.

In addition to the end and transient effects, the general deformation of the extrudate (bending and twisting) is also a critical tooling/process design consideration. This general extrudate deformation can be captured using the Arbitrary Lagrangian Eulerian (ALE) method, which has recently been the focus of additional development effort. Using the ALE method, only the free surface of the extrudate is updated based on the velocity field. The updating scheme for the geometry and important state variables, such as temperature and strain, can be further divided into steady state or incremental approaches. At the current stage of development, the computational requirement for the steady state approach is much less than the incremental one. However, the solution based on the incremental approach is more stable. Generally speaking, the ALE method is much more computationally efficient than the UL method.

Preparing a FEM model for ALE analysis, especially for hollow parts involving a bridge die (or porthole die), is a tedious and time consuming process. Since the tooling geometry is already available from the CAD/CAM system, a special facility was developed (Figure 3) to generate the workpiece geometry for an ALE simulation directly from the tooling geometry. To further enhance the data preparation for extrusion simulations, a special purpose pre-processor was also designed and developed. This paper presents the recent advances in DEFORM, including the general philosophy,
considerations, strategy, and methodology to develop a commercially viable modeling system. Detailed discussions of the predicted material flow and tooling stress for the real extrusion process, as well as the solution behavior using different modeling techniques, are also presented.

Figure 1: Industrial extrusion process: (a) Initial billet and tooling; (b) end view of the extruded product in the model; (c) real extruded product

Figure 2: Predicted material flow during the extrusion process: (a) Initial stage; (b) extrusion of legs; (c) extrudate coming out of die chamber.

Figure 3: Schematic illustration of ALE model generation: (a) Extrusion die; (b) extracted workpiece; (c) elongated extrudate; (d) actual 3D ALE example extracted from the tooling geometry; (e) vertical wall distortion predicted by the ALE method.

References:
Investigation of Conclad Extrusion and Multi-Billet Extrusion

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Abstract

In Nihon University, Conform continuous extrusion and new extrusion processes which are called multi-billet extrusion have been investigated last ten years. Conclad extrusion which was developed from Conform continuous extrusion[1], is applied to manufacturing trolley wire for train in Japan. The trolley wire which is copper covered steel wire has shorter life cycle than expected one because of corrosion for acid rain. The quality of welding part of copper must be improved. In this paper, it is investigated how to decrease involving oxide films in welding part by experimental method. On the other hand, the multi-billet extrusion[2] is applied to manufacturing automotive frames, especially impact attenuators. The developed extrusion process has been done under experimental condition. However, it is capable to vary geometries of rib which is in the inside of closed profile extruded products by this process.

Fig.1 shows experimental modules for Conclad extrusion. The extrusion force is given by the friction force between rotational grooved wheel and feedstocks. They accumulate at the front of abutments and change direction to the chamber. In these modules, two feedstocks are supplied and joined to each other in the chamber. A string(core material) is coverd by feedstocks(concluding material) and is extruded thorough the die with them. If any impurities, such as oxide film and dead metal, are involved in welding surface, the strength of welding part becomes decreasing. Therefore, the geometries of chamber have been investigated in order to reduce the volume of dead metal and to make metal flow in the chamber smooth.

![Figure 1: Schematic illustration of Conclad extrusion and streamlines in the chamber.](image-url)
Fig. 2 shows experimental equipment of multi-billet extrusion, which has two round billets and an entrance of rib between two containers. These billets are puched to the container by each stepping motors and a rib is supplied from the rib entrance between billets.

![Experimental modules for two-billet extrusion of an ideal beam with a zigzag rib.](image)

**Figure 2:** Experimental modules for two-billet extrusion of an ideal beam with a zigzag rib.

Fig. 3 shows a extruded product whose rib is acrylic acid resin and circular pipe is modelling clay. The condition of bonding is good and the extrusion process is steady state. If the extrusion temperature of rib is lower than one of circular pipe, the condition of extrusion is similar to the experimental condition.

![Extruded product with straight rib of acrylic acid resin.](image)

![An ideal beam with a zigzag rib.](image)

**Figure 3:** Extruded product with straight rib of acrylic acid resin.  
**Figure 4:** An ideal beam with a zigzag rib.

Fig. 4 shows an ideal beam with a zigzag rib which will be manufactured by multi-billet extrusion method. The geometries of this rib are optimized in the absorption energy for impact protection by numerical simulation[3].

**References:**


Advanced technologies used in the manufacture of products from aluminium alloys powder in extrusion process

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Abstract

The subject of the research was an alloy AlZnMg and AlCuMg with addition of Zr and Ag manufactured of powders by hot plastic consolidation in process of direct extrusion. Paper also presents results of research of structure evolution and mechanical properties for different tempers of precipitation strengthening and further plastic deformation, including hydrostatic extrusion.

The method of hot plastic consolidation, which is an object of the present research and some time ago became a worldwide used technique, consists in integration of materials fabricated by various processes of rapid solidification (atomisation, melt spinning) during hot extrusion process [1,2,3]. In the said process, the effect of temperature, pressure and deformation result in consolidation of powders and ribbons into material characterised by density approaching the theoretical value [4]. The method of hot plastic consolidation is used in fabrication of materials which, when manufactured by conventional metallurgical methods, are not capable of satisfying the imposed requirements, or cannot be manufactured in any other way.

In this study, the technological investigations have aimed at an achievement of the possibly highest content of Zr in solution $\alpha$, which effectively promotes structure refinement and arrests recrystallisation at high temperatures, eliminating or reducing the occurrence in structure of coarse precipitates of $\text{Al}_3\text{Zr}$ phases, harmful to the process of plastic working (reducing alloy plastic properties) [5,6].

Investigations of the manufacturing process of aluminium alloys from powders by the method of hot plastic consolidation were carried out on AlZnMg and AlCuMg alloys. The starting product in the form of powder was subjected to hot plastic consolidation. The process of hot plastic consolidation was carried out on a laboratory vertical press of max. 0,6MN capacity, using specially designed and manufactured tools [7,8]. The established and checked under laboratory conditions, parameters of the hot plastic consolidation process during direct extrusion served as a guideline in designing of equipment and establishing parameters for a half-technical scale research. The half-technical scale trials were carried out on a horizontal direct and indirect hydraulic press of 5MN maximum capacity operating at IMN OML Skawina, Poland. The stock (powder) for extrusion was subjected to preliminary compaction on a 2,5MN vertical press; the “billets” assigned for hot direct extrusion had the dimensions of $\phi$100x250mm. The next stage of plastic working of this stock was hydrostatic extrusion. In this specific case, the values of the extrusion ratio are much higher than in the process of direct extrusion. The obtained stock was subjected to structure examinations and testing of mechanical properties. The structure was examined under the optical light microscope and transmission electron microscope.

The results of examinations of structure evolution in AlZnMg and AlCuMg alloy fabricated by hot plastic consolidation of powdered stock indicate that materials fabricated by this method are characterised by ultra-fine grain and nanometric structure (Fig. 1, 2) with mechanical properties exceeding standard level. Obtained results $R_m$ above 710MPa (for AlZnMg alloy) and above 540MPa (for AlCuMg alloy) shows significant possibilities of manufacturing from Al alloys powders products with ultrafine grain and nanometric structure which properties exceeding alloys manufactured with standard methods.
Fig. 1. Example of microstructure (TEM) in rods (cross-section) extruded by hydrostatic technique from AlZnMg alloy (average grain size – 160nm) and histogram of grain size distribution.

Fig. 2. Example of microstructure (TEM) in rods (cross-section) extruded by hydrostatic technique from AlCuMg alloy (average grain size –200nm) and histogram of grain size distribution.

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