**PRESSURE TREATMENT OF METALS / ОБРАБОТКА МЕТАЛЛОВ ДАВЛЕНИЕМ**

UDC 621.777
https://doi.org/10.17073/0021-3438-2023-3-67-78

Research article
Научная статья

# Using simulation to design tool for pressing of hollow profiles from aluminum alloys

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**Abstract:** In order to simulate the pressing of hollow profiles made from aluminum alloys, the previously developed design algorithms for the pressing tool and the QForm software were utilized. The objective of this study was to enhance the quality and decrease the design time intervals for pressing tools used in the industrial production of aluminum alloy profiles. A novel design procedure for a combined tool, along with the technology of semi-continuous pressing with welded hollow profiles made from aluminum alloys, was proposed. This was achieved using the QForm software, which enables efficient calculations and adjustments of pressing parameters and tool geometry through a dialog interface. The developed algorithm and design procedures enable the drawing of hollow profiles, technological calculations of pressing parameters, selection of a suitable horizontal hydraulic press, matrix and splitter design, determination of strength parameters, assessment of equipment load, and preparation of working drawings for the pressing tool. In order to validate the effectiveness of the design procedure, it was applied to typical hollow profiles fabricated on a commercial scale. Two variations of the pressing tool design were examined. Simulation results obtained from QForm Extrusion software, specifically designed for pressing analysis, revealed that the initial design of the tool, with predetermined technological parameters and geometry of the splitter and matrix channels, resulted in uneven flow of profile elements and temperature distribution. However, by adjusting the tool parameters, it was possible to achieve a straight profile exit from the matrix and a uniform temperature distribution across its cross section. Industrial verification of the designed tool, utilizing a 33 MN hydraulic horizontal press for pressing profiles made from alloy 6063, demonstrated that significant modifications to the matrix and splitter were not necessary. By employing the proposed pressing tool design, batches of products were successfully manufactured in compliance with the required technical specifications, while reducing the design time intervals of the pressing tool by approximately 50 %.

**Keywords:** aluminum alloys, hollow profiles, pressing, horizontal hydraulic press, combined tool, technological calculations, design methods and procedures.

**Acknowledgement:** We acknowledge the support provided by the Governmental contract of Siberian Federal University, Project FSRZ-2020-0013.

For citation: Sidelnikov S.B., Koloskov S.S., Dovzhenko N.N., Gorbunov Yu.A., Voroshilov D.S. Using simulation to design tool for pressing of hollow profiles from aluminum alloys. *Izvestiya. Non-Ferrous Metallurgy*. 2023;29(3):67–78.
https://doi.org/10.17073/0021-3438-2023-3-67-78

# Применение моделирования при проектировании инструмента для прессования полых профилей из алюминиевых сплавов

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**Аннотация:** Для моделирования процесса прессования полых профилей из алюминиевых сплавов использованы разработанные ранее алгоритмы проектирования прессового инструмента и программный комплекс «QForm». Целью проведенных исследований являлось повышение качества и снижение сроков проектирования прессового инструмента для промышленных условий производства профилей из алюминиевых сплавов. Предложены новая методика проектирования комбинированного инструмента и технологии для полунепрерывного прессования со сваркой полых профилей из алюминиевых сплавов с помощью программного комплекса «QForm», который позволяет в диалоговом режиме оперативно проводить многовариантные расчеты с последующей, если необходимо, корректировкой технологических параметров прессования и геометрии инструмента. Созданы алгоритм и процедуры проектирования, которые дают возможность выполнить чертеж полого профиля, осуществить технологические расчеты параметров прессования и выбор горизонтального гидравлического пресса, спроектировать матрицу и рассекатель, провести прочностные расчеты, определить силовую загрузку оборудования и подготовить рабочие чертежи прессового инструмента. Для проверки работоспособности разработанной методики проектирования приведен пример ее реализации для одного из типовых полых профилей, изготавливаемого в промышленном производстве. Рассмотрено проектирование двух вариантов прессового инструмента. С помощью моделирования с использованием программы «QForm Extrusion», предназначенной для анализа процессов прессования, установлено, что первый вариант конструкции инструмента при заданных технологических параметрах и геометрии каналов рассекателя и матрицы приводит к неравномерности истечения различных элементов профиля и температур. В результате проведенной корректировки параметров инструмента удалось добиться прямолинейности выхода профиля из матрицы и равномерности распределения температур по его сечению. Промышленное опробование спроектированного инструмента на гидравлическом горизонтальном прессе с усилием 33 МН для прессования профиля из сплава 6063 показало, что существенной доработки матрицы и рассекателя не требуется. С применением предложенной конструкции прессового инструмента получены партии продукции, соответствующей требованиям действующих технических условий, при этом сроки проектирования прессового инструмента сокращены практически в 2 раза.

**Ключевые слова:** алюминиевые сплавы, полые профили, прессование, горизонтальный гидравлический пресс, комбинированный инструмент, технологические расчеты, методика и процедуры проектирования.

**Благодарности:** Работа выполнена в рамках государственного задания на науку ФГАОУ ВО «Сибирский федеральный университет», номер проекта FSRZ-2020-0013.

**Для цитирования:** Сидельников С.Б., Колосков С.С., Довженко Н.Н., Горбунов Ю.А., Ворошилов Д.С. Применение моделирования при проектировании инструмента для прессования полых профилей из алюминиевых сплавов. *Известия вузов. Цветная металлургия*. 2023;29(3):67–78. https://doi.org/10.17073/0021-3438-2023-3-67-78

## Introduction

Currently, the primary approach for manufacturing hollow aluminum profiles involves the utilization of a semi-continuous pressing method with a combined tool [1—7]. This method entails pressing profiles with a welding process at the center of deformation, using a combined tool consisting of a matrix and a splitter. The matrix shapes the outer contour of the profile, while the splitter forms its inner contour. During the pressing operation, a workpiece is inserted into a container and divided into multiple metal flows by the splitter. These metal flows are then directed into the welding chamber, where they are fused together under high temperatures and pressure to form a hollow profile with the desired cross-section.

Ensuring uniform outflow velocities of different profile elements from the matrix is crucial for producing high-quality pressed items during the pressing process. Significant variations in element velocities can lead to various defects such as twisting, waves, deflections, and barrels. These defects may persist even after subsequent corrective measures such as tensioning. Thus, achieving the correct positioning of the profile on the matrix mirror and implementing effective working braking bands on different segments of the tool are important considerations in pressing tool design. In addition to improving the quality of aluminum alloy profiles, it is necessary to enhance production efficiency.

To increase efficiency, reducing order fulfillment time by minimizing idle time and optimizing operations at all stages of production is a promising approach. Rapid adjustment and quick initiation of repeated precoders are key factors in achieving this goal.

Extensive research has been conducted on pressing techniques, as evidenced by numerous studies [8—20]. However, to date, there is a lack of an established procedure and software specifically designed for the design of tools and the technology of semi-continuous pressing for hollow profiles made from aluminum alloys using a combined tool.

Scientific and technical publications indicate that the most suitable software for practical application in this area is INPRESS CAD [21]. This software consists of four subsystems, each equipped with calculation and design procedures that facilitate the preparation of documentation for the implementation of specific technological processes. One of these subsystems focuses on the design of solid profiles from aluminum alloys. It enables the calculation of calibrating bands, the creation of drawings for matrices, prechambers, substrates, and other types of pressing tools, as well as the determination of force conditions and the selection of equipment for semi-continuous pressing of aluminum alloys. Additionally, there exists a subsystem dedicated to the design of pressing tools and the fabrication technology of hollow profiles. However, despite its potential, the use of this software is limited due to the complexity of the procedures involved in designing matrices and splitters. These procedures cannot be easily formalized or automated. As a result, combined tools are currently designed using an interactive approach, relying on the expertise and experience of professionals in the field, such as designers and technologists [22—25].

Furthermore, the simulation of pressing processes is currently carried out using the QForm Extrusion software [26] developed by Kvantorform company, Moscow, Russia. This software is based on the finite element method and offers several advantages. It enables the simulation of metal flow during pressing operation and provides an estimation of profile quality [27; 28]. Moreover, it takes into account for the influence of tool deformation on the pattern of profile outflow. One of the notable benefits of QForm Extrusion is its ability to rapidly calculate these processes, surpassing other comparable software such as DEFORM 3D. This allows the quick execution several of multiple calculations and significantly reduces the time required for tool design and implementation.

The objective of the conducted studies was to enhance the quality of aluminum alloy profiles and reduce the design intervals for pressing tools in industrial manufacturing conditions using QForm software.

## Experimental

In general, the design procedure and calculation of pressing technology for hollow profiles follows a similar process to that of solid profiles [21]. The procedure can be broken down into the following steps:

1) formation of the profile's normal drawing:
   - — creation of a normal drawing of the profile;
   - — perform typical calculations such as perimeter, surface area, circumcircle diameter, etc;
   - — coordinate the drawing with the customer;

2) technological calculations and selection of main pressing parameters:
   - — determine the extrusion process settings;
   - — conduct preliminary calculation for pressing force and select the appropriate hydraulic press and number of channels;
   - — calculate the workpiece length;

3) design of matrix set:
   - — determine the allowances for profile sizes;
   - — position the profile on the matrix mirror;

4) design of the splitter (boxes, tab, input region on the splitter, and other relevant components);

5) design of the matrix (welding chamber, prechamber, presetting of fillet and angle of output zone, and other necessary elements);

6) verification of strength calculations and assessment of console elements of the tool;

7) adjustment of calibrating bands on the matrix and the splitter;

8) design of the substrate, special substrate, and any other required components;

9) preparation of the working drawing for the pressing tool;

10) calculation of the pressing force and selection of an appropriate press.

By applying this design procedure, significant reductions in production preparation time and metal consumption for tool adjustment can be achieved (see Fig. 1). Ultimately, this leads to a reduction in the overall production costs of the final products.

## Results and discussion

Let us illustrate the application of the proposed design procedure through a practical example involving a standard profile made from aluminum alloy 6063, as depicted in Fig. 2. The profile comprises two distinct planes: square *1* (representing the first part) and rectangle *2* (representing the second part). The wall thickness remains consistent at 1.25 mm along the entire perimeter, while the surface area of the transverse cross-section measures 450 mm$^2$.

Upon completion of the normal drawing, a 33 MN hydraulic press was chosen for the pressing operation, with an extrusion coefficient of 106. The initial geometrical parameters and technological conditions for simulating the pressing process were then set as follows:

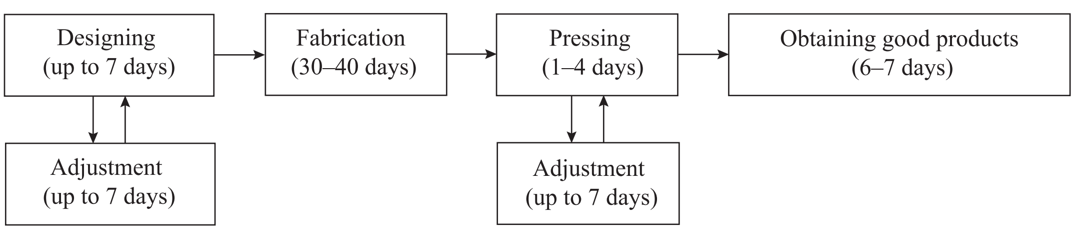


**Fig. 1.** Sequence of design procedures of the tool using QForm Extrusion simulation software

**Рис. 1.** Схема последовательности процедур проектирования инструмента с применением программы компьютерного моделирования «QForm Extrusion»

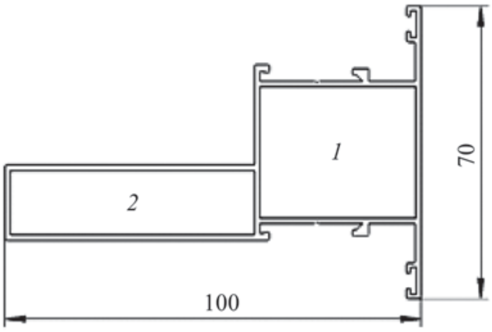


**Fig. 2.** General view of profile from alloy 6063

**Рис. 2.** Общий вид профиля из сплава 6063

a container diameter of 247 mm, a workpiece (ingot) diameter of 242 mm, a length of 1000 mm for the workpiece, a workpiece temperature of 450 °C, a matrix set temperature of 480 °C, a container temperature of 430 °C, and a pressing velocity of 2 mm/s.

The boundary conditions for calculating friction stresses at the contact between the metal and the tool were determined using the Levanov equation [26; 27]. The rheological and thermal technical properties of alloy 6063 were obtained from the library within the QForm Extrusion software.

The pressing tool material used was Grade 4Kh5MFS steel, chosen for its superior heat resistance in compliance with the specifications for hot pressing. The material hardness was measured at $HRC = 55 \div 58$.

Figure 3 presents the 3D models of the tool for the selected profile. The first model (Fig. 3, *a*), represents the initial configuration used for simulation, while the second model (Fig. 3, *b*) shows the adjusted configuration based on the results obtained from the simulation.

The diameter of the sets used in the pressing process was 340 mm. Each splitter was equipped with 6 boxes, which effectively divided the continuous workpiece into 6 metal flows. These individual flows were subsequently combined within the welding chamber, resulting in the formation of 7 joints along the entire profile length. In the second design iteration, specific adjustments were made to ensure an equal amount of metal flowed through each box per unit of time. This was achieved by increasing the total surface area of the splitter boxes at the input to 11416 mm$^2$. Furthermore, the extrusion at the input of the splitter was reduced to 4.2 units. As a consequence, these modifications improved the overall strength of the tool and led to a decrease in the required pressing force.

Following the development of the 3D model using QExDD software, a grid was generated for the calculation region and the tool using QShape software, as depicted in Fig. 4. The models were represented by triangles, with the initial design consisting of approximately 825 000 elements, and the second design consisting of around 900 000 elements. Once the grid was generated, the models were imported into QForm Extrusion software. Within the QForm Extrusion software, the main process parameters, rheological and thermal technical properties of alloy 6063, and boundary friction conditions were defined. Subsequently, the necessary calculations were performed using these predefined parameters and conditions.

Figure 5 presents the velocity distribution at different elements of the profile obtained using QForm Extrusion software with the first design of the tool. It is observed that the velocity of the square part of the profile (part 1) is measured at 220 mm/s, and there is no deviation from straightness. However, the velocity of the rectangular segment of the profile (part 2) is actually approximately half of that, resulting in the occurrence of defects.

During the analysis of the metal temperature across the profile elements (Fig. 6), it was determined that when utilizing the initial design of the pressing tool, the temperature distribution is non-uniform and ranges from 520 to 570 °C. Such variation in temperature can result in thermal deformation of the profile, as well as potential overheating and the formation of thermal cracks in specific segments of the profile, particularly at higher temperatures.

The calculations of the stress-strain state revealed that the elastic deformation of the pressing tool reaches 1 mm along the pressing axis, with deflection of the working bands reaching up to ±0.5 degrees. These factors can contribute to the accelerated deterioration of the matrix component, including wear of the working bands and the potential development of cracks. Attempts to enhance the initial design of the tool such as adjusting the

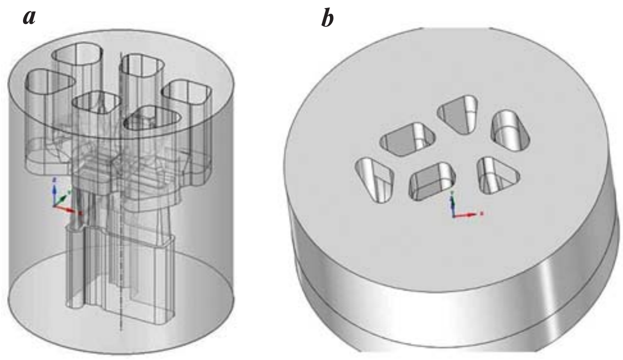


**Fig. 3.** 3D models of pressing tool
***a*** – the initial variant; ***b*** – the second variant

**Рис. 3.** 3D-модели прессового инструмента
***a*** – первый вариант; ***b*** – второй вариант

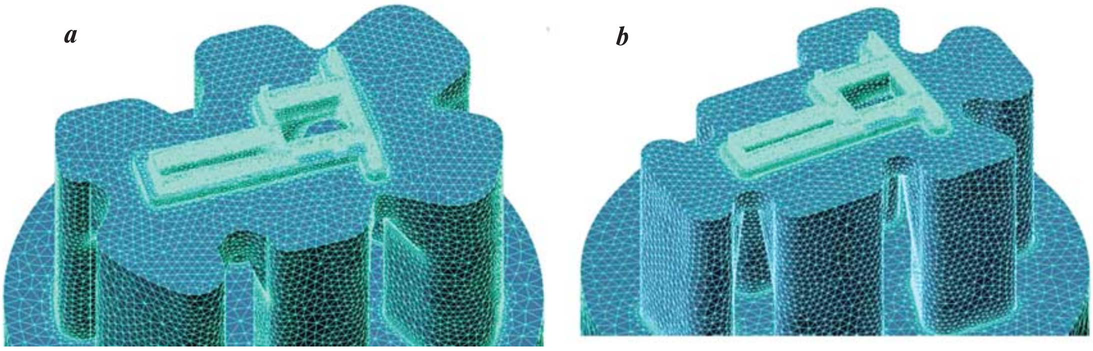


**Fig. 4.** Subdivision of calculated region into finite elements
***a*** – for the initial design of the tool; ***b*** – for the second design of the tool

**Рис. 4.** Разбиение расчетной области на конечные элементы
***a*** – для первого варианта конструкции инструмента; ***b*** – для второго варианта

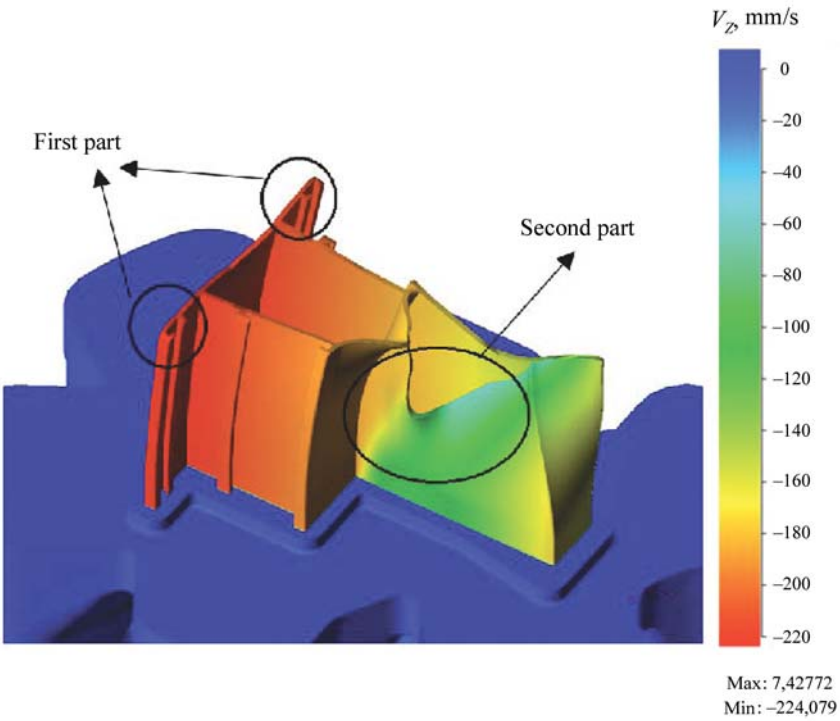


**Fig. 5.** Velocity distribution over the profile cross section for the initial tool design

**Рис. 5.** Распределение скоростей по сечению профиля для первого варианта конструкции инструмента

height of the working band or creating additional metal inflows, were unsuccessful in addressing these issues. Consequently, the decision was made to utilize the second design variant of the tool for further simulations, as depicted in Fig. 3, *b*.

The radius of the circumcircle across input boxes of the splitter remained at 210 mm, while the container diameter was set at 247 mm. As a result, defects and variations in chemical composition [29; 30] observed in the peripheral layers of the ingot were positioned outside the profile and remained in the inactive areas of the container (Fig. 7). The height of the splitter tab was reduced to 16.5 mm, thereby increasing the design rigidity and decreasing the torque due to a shorter lever arm. The difference in thickness between the working bands of the matrix and the splitter was 0.5 mm. The welding chamber and prechamber were designed using the same algorithm as in the initial tool design, with a height of 12 mm for the welding chamber and 5 mm for the prechamber. As the redesigned welding chamber had a

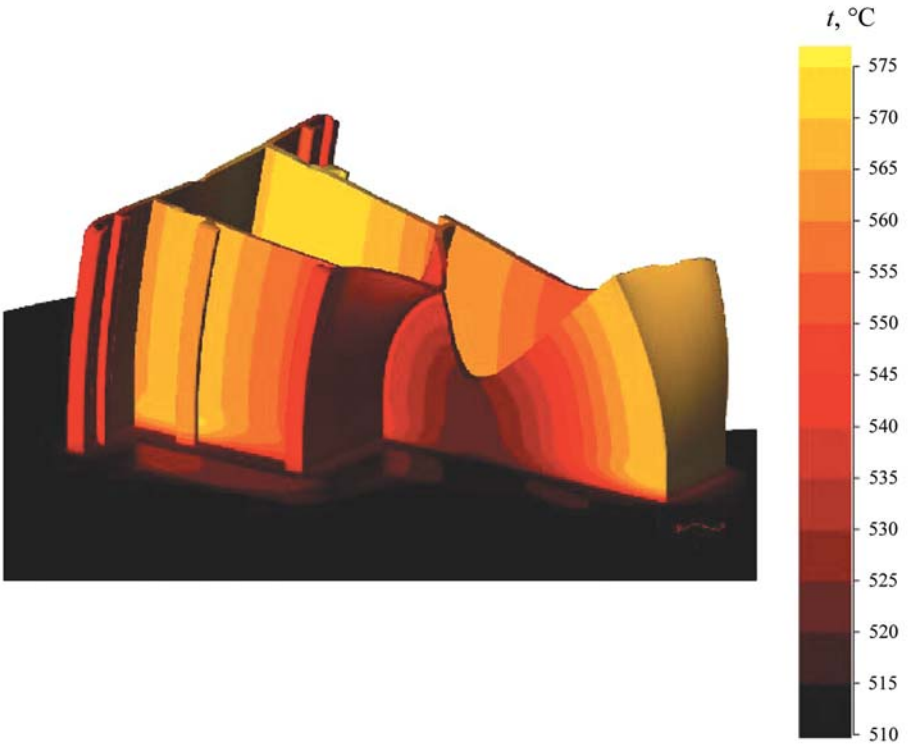


**Fig. 6.** Temperature distribution over profile elements for the initial variant of the tool design

**Рис. 6.** Распределение температур по элементам профиля для первого варианта конструкции инструмента

smaller surface area, it was expected that the changes in the shape of the splitter boxes would increase the strength of the tool. The fillet and output section of the matrix remained unchanged from the initial design. The working bands of the matrix and splitter (Fig. 8) were adjusted, taking into account the new design of the splitter boxes and the actual geometry of the profile obtained from the initial tool design.

Figures 9, 10 present the simulation results of the pressing process using the second variant of the pressing tool design, with the same technological parameters as before.

The analysis of the simulation results demonstrates that the new tool design greatly improves the homogeneity of profile outflow. However, it is observed that the metal velocity in the first part of the profile is slightly higher than the average velocity of the profile (Fig. 9). To address this, the surface area of the square box was reduced by 10 % and the height of the working band was adjusted in the subsequent simulation. The simulation results using the latest tool design (see Fig. 10) show a homogeneous velocity distribution across the entire profile cross section, with a velocity of 212 mm/s. This efficiency is further confirmed by the temperature distribution (see Fig. 11), where the temperature fluc-

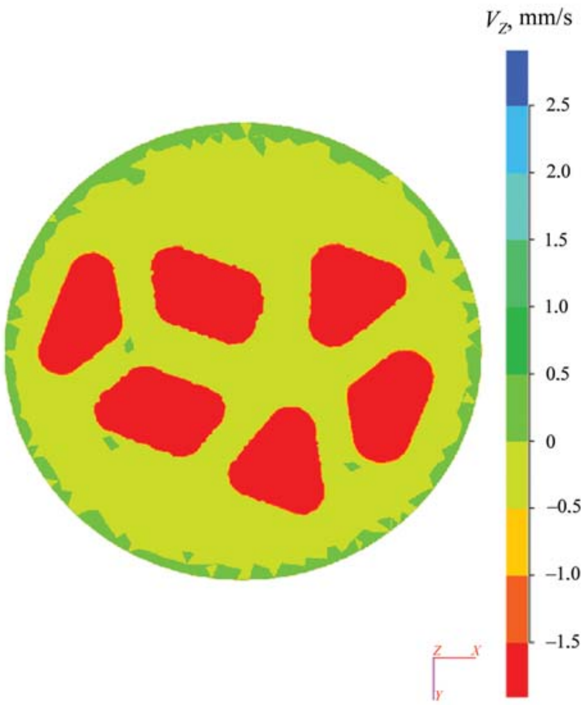


**Fig. 7.** Schematic view of formation of dead zones in container in front of input to splitter boxes

**Рис. 7.** Схема формирования мертвых зон в контейнере перед входом в карманы рассекателя

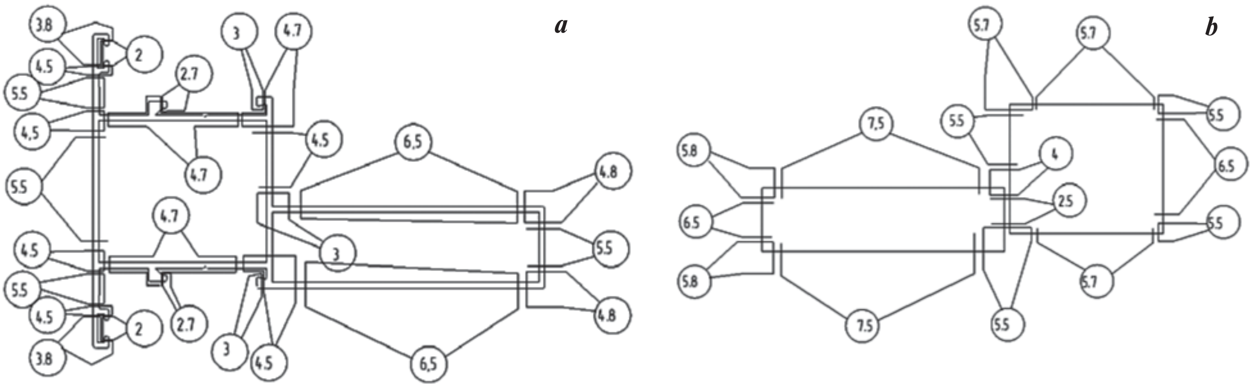


**Fig. 8.** Working bands of matrix (***a***) and splitter (***b***)

**Рис. 8.** Рабочие пояски матрицы (***a***) и рассекателя (***b***)

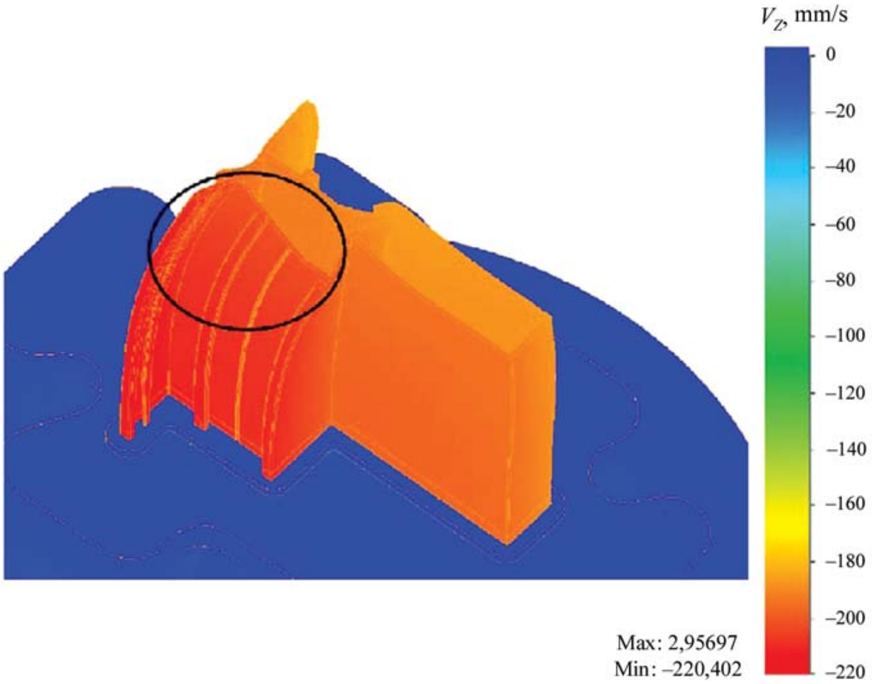


**Fig. 9.** Velocity distribution over the profile cross section for the second variant of the tool design

**Рис. 9.** Распределение скоростей по сечению профиля для второго варианта конструкции инструмента

tuation does not exceed 10 °C and the average profile temperature is 550 °C, in line with the technological specifications for semicontinuous pressing of hollow profiles from alloy 6063. In order to validate the simulation results in an industrial setting, pilot pressing of hollow profiles with the specified dimensions and alloy 6063 was conducted using a 33 MN horizontal hydraulic press at a Russian metallurgical plant. It was found that the design intervals of the combined pressing tool were effectively reduced by half, and the proposed tool design successfully produced profiles of the desired quality.

The calculated results of elastic deformation and stress intensity, obtained using QForm Extrusion software, are presented in Fig. 12. is evident that the tool undergoes significant elastic deformation during pressing, with a deflection of 1 mm along the pressing axis. Consequently, due to high stress intensity, there is a possibility of defects such as cracks.

Based on the simulation data, a decision was made to redesign the chamber at the splitter input and increase the rounding radii of the splitter. This modification led to a reduction in the loads on the tool and the required pressing force.

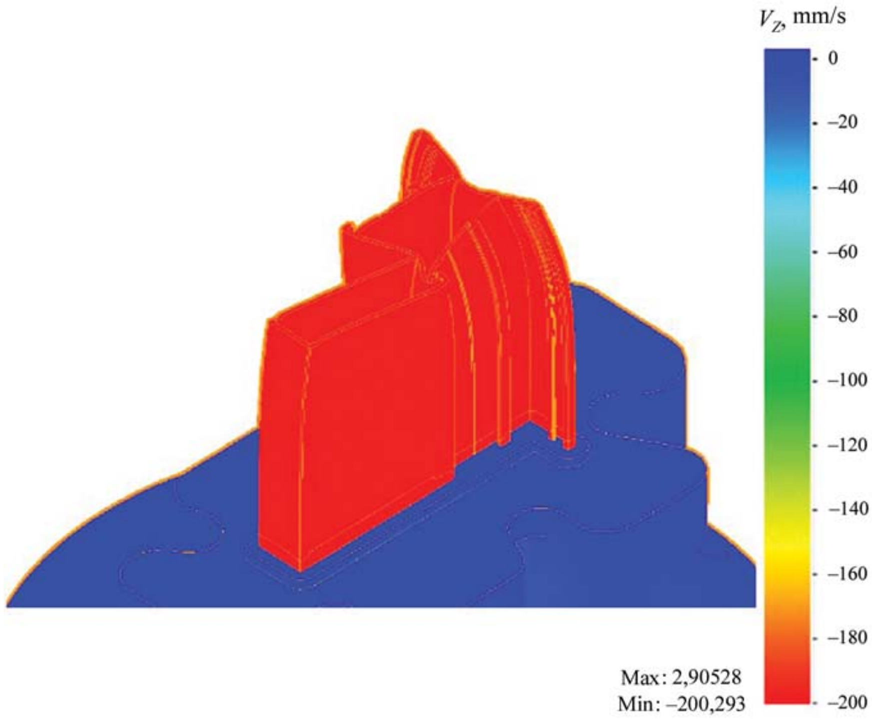


**Fig. 10.** Velocity distribution over the profile cross section for the second variant of the tool design after its modification

**Рис. 10.** Распределение скоростей по сечению профиля для второго варианта конструкции инструмента после ее доработки

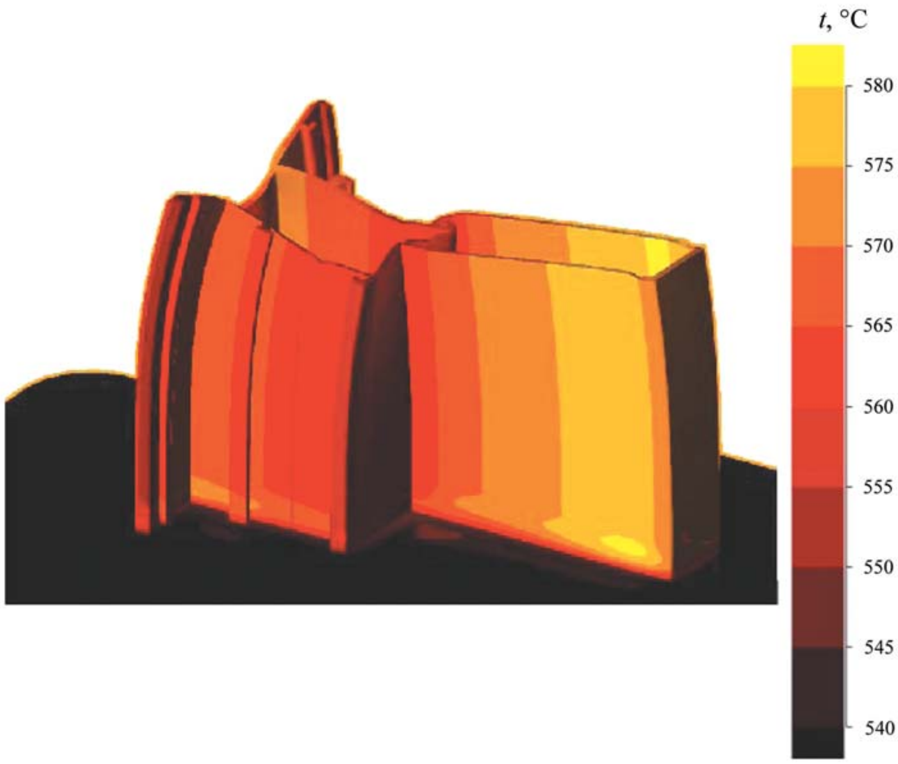


**Fig. 11.** Temperature distribution over the profile elements for the second variant of the tool design

**Рис. 11.** Распределение температуры по элементам профиля для второго варианта конструкции инструмента

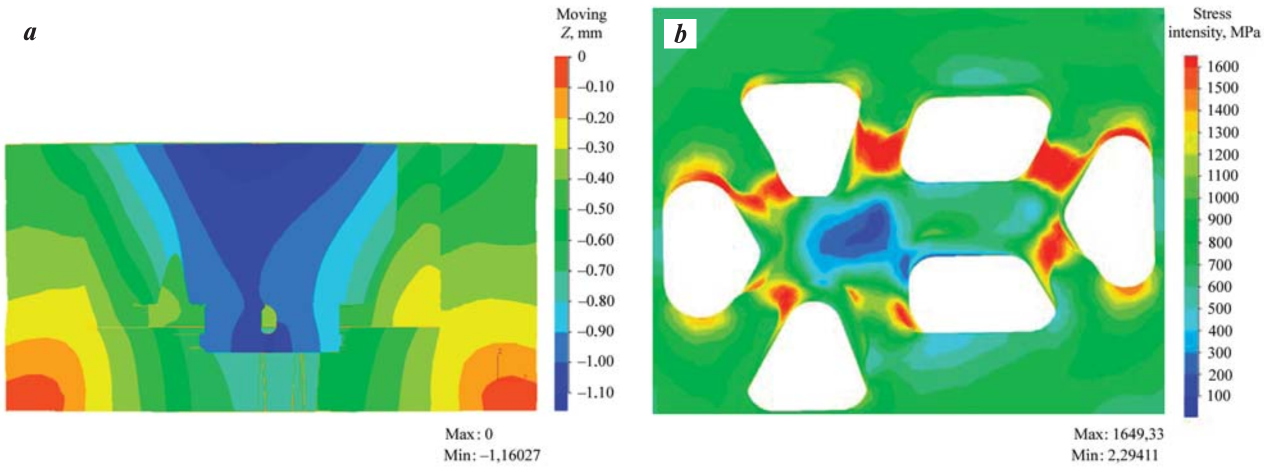


**Fig. 12.** Tool deformation (***a***) and stress intensity (***b***)

**Рис. 12.** Деформация инструмента (***a***) и интенсивность напряжений (***b***)

## Conclusions

The proposed design procedure, combined with the utilization of QForm Extrusion software, successfully simulated the pressing of hollow profiles from aluminum alloys. This approach eliminated the need for repeated adjustments of newly fabricated matrix sets through trial pressing, thereby reducing the time required for the production of new profile ranges. In order to validate the simulation results in an industrial setting (Russian metallurgical plant), pilot pressing of hollow profiles made from alloy 6063 was conducted using a 33 MN horizontal hydraulic press (see Fig. 2). The results confirmed that no major modifications to the matrix and splitter were necessary, and the proposed design of the pressing tool enabled the production of industrial-grade products that met the requirements specified in the technical specifications.

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*The article was submitted 07.02.2023, revised 12.04.2023, accepted for publication 20.04.2023*

*Статья поступила в редакцию 07.02.2023, доработана 12.04.2023, подписана в печать 20.04.2023*