Comprehensive assessment of the production of a pipe billet with a flange by forging at various temperature conditions

S B Bogdanov, A V Alekseev and Y V Gribachev
Tula State University, 92, Lenina ave., Tula, 300012, Russia

E-mail: bogdanov_stanislav1@icloud.com

Abstract. With the help of QForm simulation software, a comprehensive assessment of the production of a pipe billet with a flange is carried out. The paper studies the influence of the temperature of the die tooling on the technological extrusion force, the stress-strain state in the workpiece, as well as the change in the temperature of the semi-finished product, die and punch in the process of hot forging. The article presents the force graphs, the maximum values of the intensity of stresses and the intensity of deformations in the part, as well as the highest values of temperatures.

1. Introduction
Volumetric forging is a very common operation that produces a wide variety of parts. This method makes it possible to produce a hollow pipe billet with a flange [1], since the production of this part by means of other methods is characterized by a high production cost, low productivity of the process, or low performance characteristics of the part.

As a rule, volumetric forming takes place at hot forging temperatures [2-5], but the tool used for forming may have a different temperature. Different temperatures of the tool and the workpiece can have a significant impact on the forming of the part [6-8].

This paper studies how the temperature of the die tooling affects the process of extrusion of a hot workpiece, as well as the power characteristics of the process and the temperature distribution; it also studies the influence of the shape of the tool on the force, stress and strain state in the semi-finished product.

This research is relevant for determining the most favorable conditions for the formation of pipe billets with a flange. The aim of the work is to determine the most suitable ratio of temperature and shape of the tool for the manufacture of such products.

2. Materials and methods
As a research method, we chose computer simulation of the extrusion process in QForm software, which implements the finite element method. For the production of the part, we used hollow cylindrical workpiece with an outer diameter of 50 mm and an internal diameter of 20 mm; the height was 70 mm, the material was steel 15. The simulation regarded the billet as a rigid plastic one, the tool – as absolutely rigid one. To reduce the friction factor, lubricants were used. The initial position of the tool and workpiece is shown in figure 1, where 1 is the workpiece, 2 is the die, 3 is the punch. It is necessary to obtain a part (figure 2) with the following parameters: the size of the flange along the outer diameter is
50 mm, the thickness of the flange is 20 mm, the wall thickness of the pipe part is 10 mm, the outer diameter is 40 mm, and the length is 320 mm.

The temperature of the workpiece before the deformation is 1000°C. The temperature of the tool (die and punch) varied and at the initial moment of time equaled 20, 250 and 500°C and increased in the process of extrusion due to the heat exchange with the workpiece and due to the effect of friction. This circumstance imitates the situation when forming begins with a cold tool, and later, with an increase in the number of operations performed on this equipment, the temperature of the tooling increases [9-10]. The influence of the radius of curvature R at the operating edge of the die (figure 1), which was 1, 2.5, and 5 mm, was also investigated.

![Figure 1. 3D model of the tool and the workpiece for simulation.](image1)

![Figure 2. The resulting part.](image2)

3. Results and discussion

Figures 3-4 show the force graphs obtained during the simulation.

![Figure 3. Technological force (MN) plotted versus the die tool temperature (°C) at different curvature radii R (mm).](image3)

![Figure 4. Technological force (MN) plotted versus the curvature radius R (mm) at different temperatures (°C) of the die tooling.](image4)

According to the graph (figure 3), when the temperature changes from 20 to 500°C the force required for the processes for all the considered curvature radii R is reduced, which is associated with a reduction
of heat loss caused by the heating of the tooling, and accordingly with a higher temperature of the workpiece, as higher temperature of the material increases its plasticity.

An increase in the curvature radius $R$ of the operating edge of the die reduces the force of forming (figure 4), but the decrease is insignificant. It should be noted that increased curvature radius increases the tool life.

Next, let us consider the maximum temperatures of the tool at the initial stage of forming (figure 5) and at its final stage (figure 6).

![Figure 5](image1.png)

**Figure 5.** Maximum temperature of the tool at the initial stage of deformation plotted versus the temperature of the tool (°C) before the forming.

![Figure 6](image2.png)

**Figure 6.** Maximum tool temperature at the final stage of deformation plotted versus the tool temperature (°C) before the forming.

At the initial stage of deformation, the maximum temperature is observed on the walls of the die. At the final stage, the maximum temperatures are observed on the punch and the operating edge of the die, which is associated with heating resulting from deformation. At the final stage of the process, the maximum temperatures on the punch and on the die become equal due to the long contact of the tooling with the hot workpiece.

Next let us consider the stress and strain state for the extrusion at various curvature radii $R$ at the die tooling temperature of 500°C, since the process at this temperature is characterized by a lower technological force. Of greatest interest are certain zones of the semi-finished product (figure 2), since in these zones the highest values of stress and strain intensity are observed. Table 1 shows the maximum quantitative values of the considered parameters in zones 1 and 2, depending on the curvature radius $R$ of the tool.

| Zone  | Maximum values of stress intensity, MPa | Maximum values of the intensity of deformations |
|-------|----------------------------------------|-----------------------------------------------|
|       | R=1 mm       | R=2.5 mm      | R=5 mm      | R=1 mm     | R=2.5 mm    | R=5 mm     |
| Zone 1| 180          | 160           | 150          | 1.2        | 1.1         | 1.05        |
| Zone 2| 200          | 170           | 150          | 3.8        | 3.6         | 3.2         |
As can be seen from Table 1, stress intensities decrease with increasing radius \( R \), as well as strain intensities. Indicating that a more favorable stress-strain state occurs with larger curvature radii of the tool \( R \).

QForm software determined the parameters that characterize the damageability, and, as a consequence, is able to predict the destruction of the material as a result of the volumetric plastic deformation of the metal. The distribution of the Cocroft_Latham parameter in the semifinished product at different curvature radius \( R \) at the initial tool temperature of 500°C is shown in Figure 6.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{distribution.png}
\caption{Diagram of the Cockcroft-Latham parameter depending on the curvature radius of the operating edge of the die \( R \)}
\end{figure}

According to the diagram (Figure 7), when the curvature radius of the die \( R \) is increased it is possible to reduce the Cockcroft-Latham criterion, which indicates a decrease in damageability of the part. This circumstance positively affects the quality of the resulting product.

4. Conclusions
The results can be used as a reference when creating a technology to produce parts by means of direct extrusion methods and make it possible to choose the best forging mode in order to improve the existing technology.

The following conclusions were also made:

1. When studying the technological force of hot forging of the part under consideration, the temperature of the die tooling should be considered.
2. The temperature gradient affects the quality of the resulting product, which must be considered when setting up the die equipment.
3. With an increase in the temperature of the die tooling, a decrease in the force required for shaping is observed.
4. With an increase in the curvature radius \( R \) of the operating edge of the die, the intensity of stresses and deformations and the Cockcroft-Latham parameter decrease, which affects the quality of the product.

Acknowledgement
This work was carried out within the framework of the grant NSh-2601.2020.8.

References
[1] Yakovlev S S 2020 Analysis of methods for obtaining parts of the bushing type Bulletin of the Tula State University 12 572-576
[2] Unskov E P, Johnson W and Kolmogorov V L 1983 Theory of the plastic deformation of metals (Moscow: Mechanical Engineering)
[3] Pasynkov A A, Boriskin O I and Larin S N 2018 Theoretical studies of the procedure of isothermal expansion of pipes from difficult-to-form non-ferrous alloys under short-term creep mode Non-ferrous metals 2 74-8

[4] Demin V A, Chernyaev A V, Platonov V I and Korotkov V A 2019 Methodology for the experimental determination of the mechanical and plastic properties of a material under tension with elevated temperature Non-ferrous metals 5 66-73

[5] Lokesh Vendra S S, Sunkulp Goel, Nikhil Kumar and Jayaganthan R A 2017 Study on fracture toughness and strain rate sensitivity of severely deformed Al 6063 alloys processed by multiaxial forging and rolling at cryogenic temperature Materials Science and Engineering 68616 82-92

[6] Maeno T, Mori K, Ichikawa Y and Sugawara M 2017 Use of liquid lubricant for backward extrusion of cup with internal splines using pulsating motion Journal of Materials Processing Technology 244 273-81

[7] Dobromyslov AnV and Taluts N I 2017 Structure of Al–Fe alloys prepared by different methods after severe plastic deformation under pressure Phys. Metals Metalloagr 118 564-71

[8] Springer P and Prahl U 2016 Characterisation of mechanical behavior of 18CrNiMo7-6 steel under warm forging conditions through processing maps analysis Journal of Materials Processing Technology 237 216-34

[9] Zhengyang Cai, Min Wan, Zhigang Liu, Xiangdong Wu, Bolin Ma and Cheng Cheng 2017 Thermal-mechanical behaviors of dual-phase steel sheet under warm-forming conditions International Journal of Mechanical Sciences 126 79-94

[10] Alves L M, Afonso R M, Silva C M A and Martins P A F 2017 Boss forming of annular flanges in thin-walled tubes Journal of Materials Processing Technology 250 182-9