Current trends in the development of metal forming

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Abstract. Current trends in the development of metal forming methods are considered. Along with the increase in production volumes, the tasks of quality improvement, expansion of the product mix and energy costs reduction are becoming more and more important. To solve the set tasks, the most promising methods are combined processing, such as rolling-pressing, casting-rolling-pressing. The combination of different processing methods in one process allows conditions for the production of new profiles to be created, energy consumption to be reduced. However, the lack of sophistication of the issue in theoretical terms, the few experimental data make it difficult to find optimal modes of shaping and layout of equipment when combining processing methods. To determine the energy-efficient conditions of the rolling-pressing process, the rational layout of the equipment, new dependencies are proposed. Conducted analytical studies have proved that when implementing the rolling-pressing process for each deformation condition in the roll-matrix system, there is an optimal matrix installation location that provides the maximum drawing coefficient with minimal energy consumption. The feasibility range of the combined rolling-pressing process was established, energy-efficient deformation modes were determined, taking into account the design features of the deforming unit and the shape parameters. Recommendations for the rational layout of the deforming unit equipment, carrying out the rolling-pressing process were developed.

1. Introduction
The products obtained by metal forming methods (MF) are used in almost all industries. Along with the increase in production volumes, the tasks of quality improvement, expansion of the product mix and energy costs reduction are becoming more and more important. An effective solution to the problems posed is possible when searching for new non-traditional approaches that significantly expand the capabilities of MF methods. Modern trends in the development of MF methods are combined processing methods: such as rolling – separation [1, 2], rolling and pressing [3, 4], casting and pressing [5, 6]. The combination of casting and metal forming can be considered as the most promising direction.

2. Stages of cast and roll units development
The idea of simultaneous casting of hot metal and forming a section in rotating rolls belongs to Sir Henry Bessimer, who patented the idea in 1865. The new casting–rolling process proposed by Henry Bessimer is shown schematically in figure 1.

For a long time, it was not possible to realize the processes of casting and rolling due to the problem of coordination of the continuous casting rates and metal entry into the first mill stand, which differ several times. Currently, most difficulties have been resolved, which allowed several types of cast and roll units (CRU) to be created. The structure of the unit (figure 2) includes: a continuous
casting machine, a heating through furnace or an induction installation, a rolling mill with all technological equipment.

Successful experience in the use of CRU was developed in the creation of casting-pressing, casting-rolling-pressing units for manufacturing products of high complexity and precision from non-ferrous metals and alloys. In addition to the advantages listed above, this direction can significantly reduce the production cost due to conversion of the pressing process from cyclic to continuous using less metal- and energy-intensive plants operating on the principle of active friction forces.

3. Conditions for the implementation of the rolling-pressing process

Today, the process of casting, rolling, pressing remains insufficiently studied, which complicates its practical use. The combination of casting – rolling – pressing is carried out in several stages using all kinds of tools. After casting, the workpiece is deformed in the rolls of the rolling mill by the use of a reserve of friction forces and changes the shape in the matrix installed at the deformation zone exit. The options for implementing the casting – rolling – pressing process is shown in figure 3.

The process is possible in the case when the longitudinal force created by the rollers (Q) is greater than or equal to the force required for pressing through the die (Q1). Depending on the drawing coefficient in the matrix, the force Q1 can vary over a wide range. When placing the matrix on the line connecting the centers of the rolls, Q can be found by a formula that takes into account the design features of the groove and the support from the side of the matrix.

\[
Q = p_{av} R_s a b_s \left[ 2 \mu_s - \alpha + \mu' (h_0 + h_g) \right],
\]

where \( p_{av} \) – the average normal stress, MPa; \( b_g \) – groove width, mm; \( R_s \) – rolling radius, mm; \( \mu_s \) – the coefficient of friction at the steady state stage of the process \( h_g \) – groove height, mm; \( h_0 \) – initial strip thickness, mm; \( \alpha \) is the angle of capture, rad; \( \mu' \) – coefficient taking into account friction on the side walls of the groove.

Using formula (1), we can determine the pressure on the surface of the matrix \( (\sigma_1) \):

\[
\sigma_1 = \frac{p_{av} R_s a}{h_g} \left[ 2 \mu_s - \alpha + \mu' (h_0 + h_g) \right].
\]
When implementing the rolling-pressing process, grooves of various designs are used [7]. If the side surfaces of the groove are part of the roll, then the friction forces on them with respect to the workpiece will be active. When using fixed side groove elements, reactive friction forces will act on the workpiece from their side. In the first case, $\mu' = \mu_s$, in the second – when using one fixed plate $\mu' = \mu_s - \mu_2$ ($\mu_2$ is the friction coefficient on the surface of the fixed plate); with two fixed plates $\mu' = -\mu_2$.

With the increase in the distance from the line connecting the centers of the rolls to the matrix (x), the position of the resultant normal and tangential friction forces changes, the angle of their application, the active area increases. Changes in the force parameters of the deformation zone with increasing distance x leads to an increase in the longitudinal force. On the other hand, increasing the distance x increases the area covered by the matrix, thereby reducing the total drawing coefficient.

4. Analytical studies of the deformation conditions, the equipment layout for energy-power parameters of the rolling-pressing process and the scope of feasibility

Let us consider the influence of the position of the matrix relative to the line connecting the centers of the rolls, for example, deformation of a 13x15 mm sample in a closed groove without release with dimensions $h_r = 9$ mm, $b_r = 15$ mm, rolling radius 150 mm, friction coefficient at the steady-state stage of the process 0.5, deformation resistance 100 MPa, speed 0.5 m/s. To establish the influence of the design features of the grooves on the pressing force, we consider a groove, the side walls of which are part of the roll, a groove where one side wall is formed by a fixed plate, and a caliber with two side fixed plates. The coefficient of friction on the surface of the fixed plates is 0.15. Using the results of [8], we determine the increment of the force ($\Delta Q$) and pressure ($\Delta \sigma$) when the matrix is removed from the line connecting the centers of the rolls (x) for the known groove designs using the formulas

$$\Delta Q = p_o x \left[ 2\mu h_g + \frac{b_x x}{R_g} \right] + \mu \left( 2h_g + \frac{x^2}{R_g} \right),$$

$$\Delta \sigma = \frac{p_o R_g x}{h_g + x^2} \left[ 2\mu + \frac{x}{R_g} + \frac{\mu' \left( 2h_g R_g + x^2 \right)}{b_g R_g} \right].$$

Figure 4 shows the calculated values of the force and pressure on the matrix obtained using formulas (3), (4) for the conditions of forming in caliber without fixed plates. According to Figure 4, an increase in the distance (x) leads to an increase in the force created by the reserve of friction forces, while the pressure on the surface of the matrix ($\sigma_1 + \Delta \sigma$) first increases and then decreases, which is associated with a nonlinear change in the area of the overlapped matrix.

In the groove, the side walls of which are fixed plates, with the increase in distance (x) the same changes in the studied parameters are observed, only the values are smaller due to the reactive action of friction forces on the side walls of the caliber. Using the formulas given in [8, 9], it is possible to determine the change in the total drawing coefficient in the roll-matrix system for different values of distance (x). The calculation results are shown in figure 5, from which it can be seen that for various conditions of the process there is a certain place for the matrix to be installed relative to the rolls, which guarantees the maximum drawing coefficient. The use of fixed elements in the caliber design reduces the efficiency of the process.

Let us consider how the distance (x) affects the power parameters of the casting-rolling-pressing process. According to figure 5, the total drawing coefficient 17 in the roll-matrix system can be obtained by setting the matrix in any place at a distance (x) from 7 to 27 mm relative to the line connecting the centers of the rolls. Let us find how in this case the energy-power parameters of the process change.

The calculation results are shown in figure 6, from which it follows that for the case under consideration, the distance x = 7 mm is optimal from the point of view of energy consumption; with an increase (x) from 7 to 27 mm, the process will be feasible, but at the same time, energy consumption
will increase up to 1.7 times. Despite the fact that the distance \( x = 7 \) mm is optimal from the point of view of energy consumption, it is risky to carry out the process under these conditions, since the slightest change in the conditions can transfer the process to the area of impracticability. Therefore, the distance \((x)\) from 8 to 10 mm can be considered optimal. In this case, energy consumption will increase by no more than 5%, but process stability will be ensured.

\[ \text{Figure 4. The effect of the matrix positioning on the magnitude of the force and pressure on the matrix.} \]

Let us summarize the results obtained in the form of a graph of the feasibility of the rolling-pressing process shown in figure 7. Using the graph obtained, we can evaluate rationality in terms of the efficiency of the process and the location of the matrix.

The graph in figure 7 has five areas. In the upper part there is a “region of the impracticability of the process” – these are the values of the drawing coefficients unattainable under given conditions. A narrow region of “optimal conditions” of deformation allows the best combination of the total drawing coefficient – energy consumption to be obtained.

At the same time the process is carried out with maximum efficiency. “An area with unjustified high energy costs” allows the rolling-pressing process with a given drawing ratio to be implemented, but the energy costs will be significantly overestimated (up to 1.5 ... 2 times).

\[ \text{Figure 5. The effect of the installation location of the matrix (x) and the design features of the grooves on the total drawing ratio and the area ratio.} \]
5. Conclusions
1. The prospects of using combined processes of metal forming are shown.
2. It was established that the position of the matrix relative to the rolls has a great influence on the casting-rolling-pressing process, changing such important parameters as force, pressure on the surface of the matrix, total drawing coefficient, and energy consumption for conducting the process.
3. The area of feasibility of rolling-pressing was determined and recommendations were developed for conducting the process with minimal energy consumption.

4. It is established that the use of fixed elements in the groove design reduces the efficiency of the rolling – pressing process.

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