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STUDY OF STAMPING AND ROLLING PROCESSES IN THE FORMATION OF PIPELINE FLANGES

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An innovative technological process for manufacturing pipeline flanges using the cold end-rolling method is proposed, which opens new opportunities for improving production efficiency and reducing manufacturing costs. This method significantly reduces metal consumption through the optimal use of the blank, as well as greatly diminishes the labor intensity of the technological process. Consequently, it offers significant economic advantages compared to traditional methods, which often lead to higher material waste and greater resource consumption.

The research has established that the molding process using end-rolling creates a favorable stress-deformed state in most of the deforming areas of the blank, especially in the regions beyond the central zone. This beneficial state promotes uniform load distribution, reduces residual stresses, and improves the strength characteristics of the final product. By creating a more balanced stress profile, the end-rolling process enhances the overall mechanical properties of the flange, leading to greater durability and reliability in the final product.

The cold end-rolling technology is based on sequential plastic deformation of the material by applying radial force to the blank. This ensures not only high geometric accuracy but also improved operational characteristics of the flanges. The uniform distribution of deformations reduces the risk of defects such as cracks, thinning, or warping, significantly extending the service life of the products. Furthermore, the method can achieve consistent results across a wide range of flange sizes and configurations.

Moreover, the developed process is versatile and can be adapted for manufacturing flanges of various sizes, materials, and designs, providing flexibility for different industrial applications. The technique also contributes to reducing material waste and lowering energy consumption, making it more environmentally sustainable than conventional methods. The minimized need for additional processing steps and reduced energy requirements further enhance the cost-effectiveness of this technology.

The implementation of the proposed method in pipeline industry enterprises opens prospects for increasing productivity, reducing production costs, and improving the quality of finished products. This approach represents a significant step forward in the development of modern pressure metalworking technologies, offering a more efficient and environmentally friendly solution for producing high-quality pipeline flanges.

Key words: *deformation, stamping, settling, stretching, plasticity,stamping, rolling, pipeline flanges, forming processes, metallurgy, plastic deformation, technological process, cold metalworking, pipeline industry, material properties.*

F. 4. Fig. 3. Ref. 15.

1. Problem formulation

The importance of improving the efficiency of technological processes in the production of pipeline flanges is critical to ensuring the production of high-quality and economically viable products. In modern industrial manufacturing, one of the main challenges is the significant loss of metal and the high energy consumption associated with traditional flange manufacturing methods, such as hot stamping. These traditional techniques require multiple transitions, complex tooling, and substantial energy inputs, which result in high production costs, as well as difficulties in achieving the necessary precision and consistent product quality.

The potential benefits of using cold stamping by rolling as an alternative method offer significant promise in reducing metal waste and improving the overall material utilization factor. This method holds the potential to achieve lower costs, fewer defects, and improved efficiency in comparison to conventional techniques. However, despite the promising advantages of cold stamping by rolling, there are still unresolved issues regarding the optimization of key technological parameters, such as the selection of the appropriate shape for the blanks, as well as the development of suitable deformation regimes that ensure consistency and high product quality. These challenges call for a deeper investigation into the complex interaction of frictional forces during the process, the distribution of material deformations, and the effects these factors have on the final product's characteristics.

In addition, further exploration is needed to understand how the various stages of the process can be adjusted to minimize material waste and energy consumption, as well as to enhance the mechanical properties of the manufactured flanges. Optimizing these aspects would lead to a more sustainable production process, which would be economically beneficial for manufacturers and environmentally advantageous as well. Thus, the relevance of this research lies in the development of an innovative and efficient technology for the manufacturing of pipeline flanges. Such a technology would ensure the production of high-quality products, significantly reduce material consumption and energy expenditures, and contribute to the overall improvement of the economic viability of the flange manufacturing process [12, 13, 14].

2. Analysis of recent research and publications

The formation of pipeline flanges is a crucial operation in the manufacturing of pipeline components, which are essential for the construction and operation of fluid and gas transport systems. Traditionally, the production of flanges involves various methods of metalworking, including stamping and rolling processes. These techniques play a critical role in shaping flanges with precise geometric properties and the desired mechanical strength to ensure the safety and efficiency of the pipeline systems.

This study focuses on the investigation of stamping and rolling processes applied to the formation of pipeline flanges, aiming to optimize these processes in terms of material efficiency, labor cost reduction, and product quality improvement.

The ongoing advancements in material science and manufacturing technologies have highlighted the potential for significant improvements in the stamping and rolling methods. In particular, the use of cold stamping and rolling provides several advantages, including reduced metal consumption, better control over dimensional accuracy, and the enhancement of the mechanical properties of the final product.

Understanding the principles of plastic deformation during the stamping and rolling of pipeline flanges is essential for optimizing the technological process. The behavior of materials under radial forces, the creation of favorable stress-deformed states, and the prevention of defects such as cracks and thinning are central to this study. This research aims to explore how these processes can be refined to improve the overall productivity and cost-effectiveness of flange manufacturing while maintaining the high-quality standards required for pipeline applications.

The findings of this study will contribute to the development of more efficient, sustainable, and cost-effective technologies in the production of pipeline flanges, addressing both the technical and economic challenges faced by modern manufacturing industries [1, 2, 3, 4].

Pipeline flanges are some of the most commonly used components in industrial applications, especially in the construction of pipeline systems for the transport of fluids and gases. Given their widespread use, improving the technology for manufacturing these flanges holds considerable promise for increasing efficiency and achieving substantial economic gains. A key area of focus in flange production is the increase in the metal utilization factor (MUF) and the reduction of labor intensity in the manufacturing process. Existing methods of manufacturing flange blanks using hot stamping [1] currently allow achieving a metal utilization factor (MUF) of 0.6-0.7. While this process is widely applied, it has notable disadvantages. The method requires a significant number of transitions during the manufacturing stages, resulting in high labor intensity, increased energy consumption, and the need for complex tooling. Additionally, there is a relatively high level of material waste, which makes the overall process less economically efficient.

Particularly for flanges with necks, the production method of end-rolling proves to be more advantageous. This method involves a more efficient process that results in a more streamlined manufacturing cycle. However, one of the main challenges in this approach is the selection of the optimal shape for the initial blank, as well as determining the most effective deformation schemes and technological modes to ensure the best possible outcome. The traditional stamping process involves considerable metal waste and requires several stages to reach the desired shape, which is why end-rolling becomes an appealing alternative for reducing waste and improving overall efficiency.

The primary goal of this work is to develop a technological process for manufacturing pipeline flanges using the end-rolling method. The aim is to achieve a process that utilizes blanks obtained through a waste-free separation method from a sheet, plate, or rod. This method will minimize the number of process transitions, reduce material waste, and ensure that the final products meet the required high-quality standards. The reduction in the number of transitions will directly lead to a decrease in production costs, while the higher-quality finished products will improve the operational characteristics of the pipeline systems in which they are used.

An essential aspect of achieving the goal outlined above is the discovery of the effect of active friction forces on the flow direction and intensity of the metal in the contact zone of the blank with the roll. This phenomenon leads to an enhancement in the centrifugal flow of the metal as the angle of inclination and the degree of displacement of the apex of the conical roll increase from the center of the blank [2]. These findings, supported by quantitative patterns, help in understanding how the metal behaves during the deformation process and can be used to optimize the end-rolling operation. The directed application of these friction forces allows for the reworking of the initial flat blank, transforming it through rolling to form a cavity in its central part. This process results in improved metal flow characteristics and higher material utilization, thus achieving the desired outcomes in terms of both material efficiency and final product quality.

3. The purpose of the article

The goal of this article is to investigate the processes of stamping and rolling in the formation of pipeline flanges, specifically the development of a technological process for manufacturing flanges using the cold end-rolling method. The aim is to increase the metal utilization factor, reduce labor intensity and energy consumption, as well as minimize waste and ensure the high quality of the finished products. The article examines the impact of active friction forces on the direction and intensity of metal flow in the contact zone of the blank with the roll, as well as the mechanisms that allow for the effective application of this method to manufacture flanges of various sizes and configurations.

4. Results of the researches

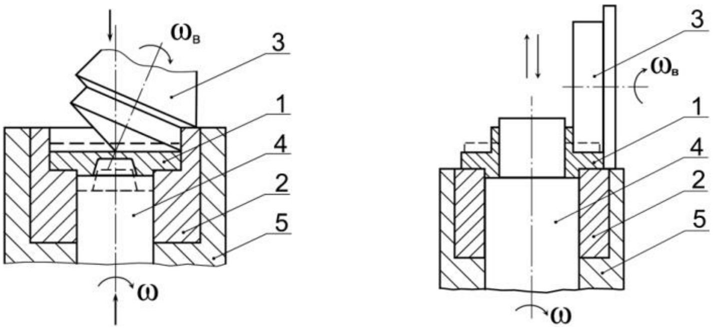
The goal set can be examined in more detail, as the use of the waste-free cutting method to obtain a flat square billet, which is then subjected to rolling by a conical roller, opens new opportunities for optimizing the production process. It is important to note that with this approach, material waste is minimized, leading to significant cost savings on raw materials. This process, implemented in a matrix with a pusher, not only saves metal but also ensures high accuracy of the flange shape, which is especially important in serial production conditions.

The conical roller, positioned at an angle to the axis of the billet, creates special conditions for material deformation. Its design and position play a key role in forming the central cavity of the flange, as the displacement of the roller's apex from the center of the billet towards the contact spot intensifies the redistribution of deformations and contributes to the creation of the required geometry of the product. This interaction of system elements allows for effective control over the deformation process, leading to improved quality of the final product [1].

Special attention should be given to the lack of direct contact between the roller and the central part of the billet. This unusual solution helps to avoid unnecessary material damage and allows the billet to undergo uniform compression around its periphery, improving its mechanical properties and enhancing the strength of the final product. At the same time, the pusher, positioned in the matrix, plays an important role in the early stages of rolling. Its shape and position, similar in size and form to the flange cavity, allow for the precise creation of the required flange shape with minimal deformations.

Additionally, the dynamic movement of the pusher towards the roller during the rolling process contributes to the accurate formation of the central hole of the flange, which is crucial for ensuring dimensional accuracy and meeting technical requirements[1, 2, 3]. Together, all these elements of the technology make the process not only more efficient but also ensure higher product quality and accuracy, while reducing labor costs and improving the economic efficiency of production (fig. 1 a).

The process of manufacturing flanges with a neck through the method of end-rolling, particularly when using a cylindrical roller in combination with a matrix and pusher, offers significant advantages in terms of material utilization and precision. The initial stage, where a flat square billet is obtained using a waste-free cutting method, ensures minimal waste generation. However, when it comes to creating flanges with necks, the process becomes more intricate and requires further steps to ensure the correct form and functionality of the final product.



a) *b)*

Fig. 1. Scheme of forming a flange blank using conical a) and cylindrical b) rolling rolls: 1 – blank, 2 – matrix, 3 – roll, 4 – pusher, 5 – spindle.

After the cavity has been formed in the initial stage, the next critical step involves removing the bridge above the formed cavity. This action is necessary because it clears the way for the subsequent shaping process where the billet will undergo a more refined deformation to form the flange neck. The cylindrical roller, positioned in the matrix with a pusher, plays a pivotal role in this stage. It ensures that the material flows smoothly, distributing the deformation forces evenly across the billet and preventing any localized strain that could cause defects, such as cracking or excessive thinning.

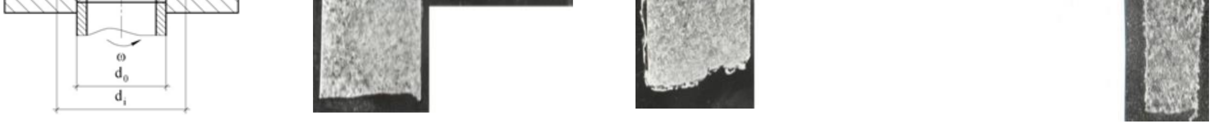
This process, as it progresses, allows for the precise formation of the neck, a critical feature of the flange that must meet both dimensional and structural integrity requirements. The pusher, which moves toward the roller during the rolling operation, further facilitates the formation of the central hole required for the flange's intended application. As the pusher moves toward the roller, it essentially helps in maintaining the correct internal dimensions of the central hole, crucial for ensuring the flange’s compatibility with the corresponding pipe or equipment [7].

Additionally, the process does not result in direct contact between the roller and the central part of the billet, which is a significant advantage in terms of minimizing material wear and tear, as well as avoiding possible damage to the billet. This unique feature ensures that the deformation is concentrated primarily on the peripheral regions of the billet, where the material is more easily shaped and manipulated. As a result, the central part of the billet remains unaffected, preventing distortion or irregularities in the flange’s final structure.

The progressive rolling with the cylindrical roller and pusher ultimately results in a high-quality flange with a neck that has the desired geometrical properties and structural integrity. This method, by optimizing material flow and minimizing energy consumption and waste, is an efficient alternative to traditional methods, offering both economic and technical benefits for flange manufacturing processes. The overall effect is a more streamlined and cost-effective production process with higher quality outcomes, making it suitable for mass production in industries such as pipeline construction and heavy manufacturing [7, 8].

When manufacturing flanges with a neck, the bridge above the formed cavity is removed from the billet obtained in the previous stage, and the billet is then rolled with a cylindrical roller in a matrix with a pusher (Fig. 1. b).

The technological scheme of planting outer flanges on pipe blanks with a conical roll is shown in (Fig. 2, a). The most dangerous, from the point of view of destruction, was the external free side surface of the flange. At the same time, the displacement of the top of the roll in the direction of the contact spot, as shown in (Fig. 2, a), contributes to the departure of the material of the peripheral part of the flange of the workpiece from contact with the roll, as shown in fig. 1,c and fully realized in (Fig. 2).



a) *b)* *c)* *d)*

Fig. 2. Scheme of planting the outer flange of the workpiece by the rolling stamping method a) and the cross-section of the formed flange b), c), d) depending on the position of the top of the roll

In this process, the side surface of the roller forms a gap with the pusher's protrusion that corresponds to the thickness of the flange neck. During the rolling process, the flange with the neck is fully formed, and the billet is removed by the movement of the pusher. The intensity of metal flow in both the radial and axial directions is controlled by positioning the deformation focus before or behind the billet's axis of symmetry in the contact plane, relative to its direction of rotation [5].

This adjustment allows for precise control over the deformation process. By varying the position of the deformation zone, it is possible to influence the distribution of the forces applied to the material, ensuring that the metal flows uniformly and without defects. Such control is particularly important when forming complex shapes, like flanges with a neck, as it ensures that the material is consistently deformed throughout the billet, minimizing the risk of material thinning or irregularities in the final product.

The design of the roller and pusher mechanism, along with the ability to adjust the deformation focus, offers significant advantages in terms of producing high-quality flanges. The method not only guarantees precision in the formation of the neck but also helps in achieving the desired mechanical properties of the flange. The ability to control the flow of material during the rolling process ensures that the flange maintains structural integrity, making it suitable for use in high-pressure pipeline systems.

Overall, this method provides an efficient, reliable, and cost-effective approach to producing pipeline flanges, particularly those with complex features like a neck. The precise control over the deformation process improves the overall quality of the products and reduces the energy consumption and material waste typically associated with traditional manufacturing techniques.

When the roll is shifted in the positive direction, that is, the contact spot shifts by an amount $\delta \succ 0$ in the direction opposite to the direction of rotation of the workpiece, the material of the deformable workpiece flows to its center. With a negative displacement of the roll, a centrifugal flow of material is observed. As the amount of displacement increases, the angle of divergence between the velocity vectors of the roll and the workpiece increases and the intensity of the metal flow in the corresponding direction increases.

The spot of contact between the workpiece and the tool is completely determined by the geometry of the roll and the amount of its displacement δ. In the case of rolling a circular workpiece with a cylindrical roller with a radius $R_в$, the surface of the instrument (Fig. 3) is described by the equation [7, 8, 9] :

$$(y-\delta)^2 + (z-R_в)^2 - R_в^2 = 0 \quad (1)$$

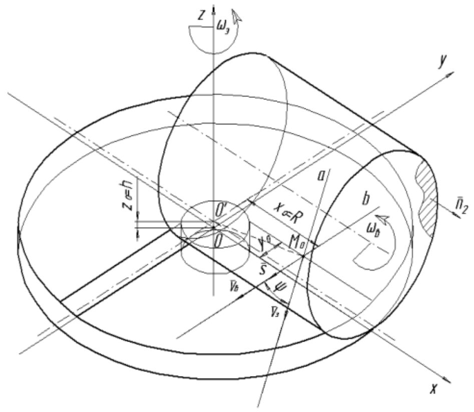


Fig. 3. Calculation scheme of the end rolling of a ring blank with a cylindrical roller for determining the angle between the projections of the velocity vectors of the contact points of the roller with the blank onto the horizontal plane.

Taking into account the accepted notations, the angle between the projections of the velocity vectors of the tool and workpiece points onto the horizontal plane in the contact patch is determined as [8,9]:

$$\Psi = arctg\sqrt{\left(-\frac{\sqrt{R_в^2-(h-R_в)^2}+\delta}{R}\right)} \quad (2)$$

The placement of the deformation focus before the axis of symmetry of the blank, relative to its rotation in the contact plane with the roller, leads to a more intense flow of metal into the gap between the roller and the pusher. On the other hand, placing the contact focus behind the axis of symmetry of the blank ensures enhanced metal flow in the radial centrifugal direction. This allows for the variation of the size and shape of the blank for the operation of forming the flange collar and other flange elements.

Due to the significant deformations involved in the reshaping of blanks, this process, aimed at reducing force parameters and improving the metal's deformability, should be conducted under hot deformation conditions. The study of the regularities of damage accumulation in metals during hot deformation was carried out using a linear model [1, 9].:

$$\psi(t) = \frac{n}{\varepsilon_{i\ p}^{0}\left[t_k^0\right]^n}\int_0^t \left[t-\tau\right]^{n-1}\dot{\varepsilon}_i(\tau)d\tau \quad , \qquad (3)$$

describing isothermal deformation under simple deformation conditions. Here is $0 \le \tau \le t$ time; $\dot{\varepsilon}_i = \sqrt{\frac{2}{3}\dot{\varepsilon}_{ij}\dot{\varepsilon}_{ij}}$ – intensity of deformation rates; t_k^0 – deformation time before failure at constant strain rate intensity ε_i^0; n – model parameter[8].

To study the change in damageability during a pause, the following process was considered: deformation with a constant value ε_i^0; until the time $t_1 \prec t_k^o$, then instant unloading associated with the cyclical nature of the rolling process, and $\varepsilon_i^0 = 0$, until the moment $t > t_1$ The accumulation of damage in this process is described by the relationship following from[7, 11, 12]. (3).

$$\psi_i(t) = \left(\frac{t}{t_k^0}\right)^n \left\{\left(\frac{t}{t_1}\right)^n \left[\left(t-t_1\right)/t_1\right]^n h\left(t-t_1\right)\right\}, \qquad (4)$$

where – $h(t) = \left[\begin{matrix} 0,\text{at}\,\tau<0 \\ 1,\text{at}\,\tau<0 \end{matrix}\right.$.

From the analysis of dependence (4) it was established that the “healing” of damage depends on the level of accumulated damage $\Psi = (t_1)$ duration of pause and the properties of the material at a given temperature, reflected by the value of the parameter n. From model (3), a criterion dependence of the maximum uniform deformation during cyclic deformation corresponding to the onset of local thinning in the center of a square blank during its reforming was also obtained. It was established that the parameter n. for the temperature range corresponding to each material, it changes according to a linear law, and when certain temperatures are reached $n \approx 1$. Thus, the rate of deformation has a noticeable effect on the deformability of blanks only up to certain temperatures.

Research has established [3] that in the process of reshaping by end rolling, a favorable stress-strain state is created on the deformable sections of the blank, except for its central part, and heating is decisive not so much for eliminating material destruction as for reducing contact stresses and deformation forces.

It should be noted that the process of forming a flange with a cylindrical roll allows the use of blanks obtained by bending round or square rods into a ring and connected by welding as initial ones [14, 15].

5. Conclusions

The innovative technological process for the production of pipeline flanges using the stamping method will ensure a high level of quality of the produced components, reaching a vicoristic material coefficient (KIM) of 0.8. This allows you to significantly reduce material costs and improve the efficiency of the manufacturing process, due to the change in the amount of metal inputs.

A study of stamping processes during the molding of pipeline flanges showed that the use of this method not only improves the accuracy of the production of parts, but also allows for a change in the complexity of manufacturing. The process is technologically simpler and more economically efficient compared to traditional methods, which requires the use of a large number of tools and complex equipment.

In addition, the stagnation of end rocking reduces the need for additional machining operations, which translates into lower waste costs for the fabrication of pipeline flanges. This is especially important for increasing the competitiveness of enterprises engaged in the production of pipeline fittings and other similar products.

Also, the propionation method is promising for the introduction of manufacturing practice, since it allows increasing the efficiency of the technological process, reducing the cost of manufacturing and the quality of the prepared products.

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ДОСЛІДЖЕННЯ ПРОЦЕСІВ ШТАМПУВАННЯ ОБКОЧУВАННЯМ ПРИ ФОРМУВАННІ ФЛАНЦІВ ТРУБОПРОВОДІВ

Досліджено та запропоновано інноваційний технологічний процес виготовлення фланців трубопроводів методом штампування обкочуванням, який відкриває нові можливості для підвищення ефективності виробництва та зниження витрат на виготовлення. Цей метод значно знижує споживання металу завдяки оптимальному використанню заготовки, а також значно зменшує трудомісткість технологічного процесу. В результаті, цей метод має суттєві економічні переваги порівняно з традиційними методами, які часто призводять до великого відсотка відходів матеріалів і більшого споживання ресурсів.

Дослідження показало, що процес формування за допомогою штампування обкочуванням створює сприятливий напружено-деформований стан в більшості ділянок, що деформуються заготовки, особливо в зонах, що знаходяться за межами центральної частини. Цей корисний стан сприяє рівномірному розподілу навантаження, знижує залишкові напруження і покращує міцнісні характеристики кінцевого виробу. Завдяки створенню більш збалансованого профілю напружень, *процес штампування обкочуванням підвищує загальні механічні властивості фланця, що забезпечує більшу довговічність і надійність кінцевого виробу.*

Технологія штампування обкочуванням базується на послідовному пластичному деформуванні матеріалу шляхом прикладання радіальної сили до заготовки. Це забезпечує не тільки високу геометричну точність, але й поліпшення експлуатаційних характеристик фланців. Рівномірний розподіл деформацій зменшує ризик утворення дефектів, таких як тріщини, витончення або викривлення, значно подовжуючи термін служби виробів. Крім того, метод дозволяє отримувати стабільні результати для широкого діапазону розмірів і конфігурацій фланців.

Більше того, розроблений процес є універсальним і може бути адаптований для виготовлення фланців різних розмірів, матеріалів і конструкцій, що надає гнучкість для різних галузей промисловості. Техніка також сприяє зменшенню відходів матеріалів і зниженню енергоспоживання, що робить її більш екологічно сталим методом порівняно з традиційними. Зменшена потреба в додаткових операціях обробки та знижені енергетичні вимоги ще більше підвищують економічну ефективність цієї технології.

Впровадження запропонованого методу в підприємствах трубопровідної промисловості відкриває перспективи для підвищення продуктивності, зниження витрат на виробництво та поліпшення якості готової продукції. Цей підхід є значним кроком уперед у розвитку сучасних технологій металообробки матеріалів тиском, пропонуючи більш ефективне та екологічно чисте рішення для виготовлення фланців трубопроводів високої якості.

Ключові слова: *деформація, штампування, осадка, розтягнення, пластичність, штампування, прокатка, фланці трубопроводів, процеси формування, металургія, пластична деформація, технологічний процес, холодна обробка металів, трубопровідна промисловість, властивості матеріалів.*

Ф. 4. Рис. 3. Літ. 15.

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