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# FINDING AN EFFICIENT SHAPE FOR THE CROSS SECTION OF THE FRONT END OF A TUBULAR SEMIFINISHED PRODUCT TO PERFORM DRAWING

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*Pipe plants use radial forging to reduce the diameter of shafts, tubes, and axles. A three-dimensional finite-element method employing the software DEFORM-3D is used to optimize the radial forging operation. Three different tool configurations are examined for obtaining smooth and folded reduced semifinished products, and suggestions are made for an efficient shape for the tubular semifinished product prior to drawing, the design of the dies, and the configuration of the tool.*
***Key words:*** *radial forging, radial forging machine, finite-elements method, DEFORM application package, deformation of metal, energy-force parameters.*

The production of tubes by drawing entails the execution of several preliminary operations. One of those operations is obtaining a "grip," i.e., a tube end of reduced diameter that is to be fed into the draw plate. Very precise requirements have been established for the geometric and strength characteristics of the grip [1]. These requirements are satisfied when the equipment is properly adjusted and the correct tool is used. However, the grip is removed after the drawing operation, and the amount of metal lost from this part of the tube accounts for as much as 30% of all of the metal lost by drawing. To increase usable output, it is necessary to not only reduce the length of the compressed part of the tube but also determine the shape of the cross section that is optimum from the standpoint of satisfying the above-noted requirements while allowing a large number of drawing passes to be made with the same grip.

Grips are formed by one of two methods – reduction of the ends of tubes on radial forging machines or formation of the grips on hydraulic pushing machines. Each of these technologies has its advantages and disadvantages. However, the deciding factor in choosing between them is the range of products that is to be made. In particular, pushing machines are not used in the production of thin-walled tubes or tubes made of nonferrous metals. In addition, attempts to increase the amount of deformation that can be achieved per pass have thus far been unsuccessful due to the instability of the front end of the tube [1]. On the whole, it is almost impossible to use the pushing operation to obtain grips with cross sections of different shapes and to thus find an efficient shape for specific sizes of tubes.

Pipe plants use radial forging machines of the AVS type to prepare tubular semifinished products for drawing. AVS forging machines makes it possible to obtain grips of different types, which can conditionally be divided into two groups: grips with a circular profile; grips with a folded profile. Circular grips are best used in the production of thick-walled tubes and tubes for which the ratio of the wall thickness to the diameter is no smaller than 1/16. Circular grips are preferable for drawing with a mandrel. Folded grips are used in the production of thin-walled tubes and tubes for which the ratio of wall thickness to diameter is no greater than 1/16. For the most part, folded grips are used when the drawing operation is performed without a mandrel.

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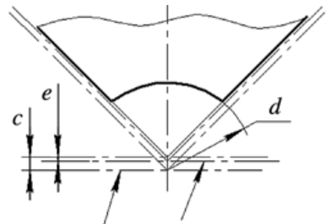


Fig. 1. Opening of the die.

The process of forging on a radial forging machine is optimized by finding the optimum shape for the die. There are two types of dies used on AVS machines. The first type has a smooth inlet surface, a reducing surface, and a sizing surface. The second type has an additional design element in the form of a rib located on the reducing surface. A cross-sectional shape that is optimum from the standpoint of decreasing the amount of metal which is consumed was proposed for grips in [2], but theoretically this shape would be almost impossible to obtain under factory conditions.

It was established that the use of a grip with a circular profile results in a gradual increase in the thickness of the wall in the drawing end of the tube. This stabilizes the drawing operation in its initial stage, when the risk of having the tube rupture inside the draw plate is greatest. A tube end of circular profile is obtained by using so-called smooth dies on the radial forging machine. Such dies consist of a conical inlet section, a conical reducing section, and a cylindrical sizing section. The diameter of the opening in the die is found from the relation

$$d = 2(0.5D_1 - e + c) - f,$$

where $D_1$ is the diameter of the grip after the forging operation; $e$ and $c$ are the distance from the deformation axis of the lateral part of the die to the axis of the forging machine and to the deformation axis of the opening, respectively; and $f$ is a parameter used to select the size of the gap between the parts of the forging machine, mm.

There are two cases in which folds may be formed on the ends of tubes during their forging on radial forging machines. In the first case, regularly shaped folds are formed when the forging operation is performed with the use of special forging dies whose working cone contains a rib-like hard-facing [3]. In the second case, folds are formed when the forging operation is done using standard dies with a smooth working cone. It was shown in [3] that the irregular shape of the folds obtained in the second case is related to loss of stability by the end of the tube. Using the well-known method developed by P. F. Pankovich, the authors of [3] proposed an expression to determine whether or not the cross section of a tubular semifinished product could become unstable during the reduction of its front end.

When folds are formed on a tube that is forged using a die with a rib, a symmetrical profile without acute angles is formed by the channels of the folds on the conical transitional section between the folds and the initial part of the tube. The presence of such a profile makes it possible to prevent rupture of the lead end of the tube during the initial stage of the drawing operation. One obvious advantage of having such a folded profile for the drawing end of the tube is that when the preparatory operations are being performed prior to drawing – specifically, pickling of the tubes and the application of a lubricant to their surface – the process liquids can flow readily through the remaining free openings even when substantial reductions have been made to the initial semifinished product.

The ribbed forging dies used to form grips with a folded profile are similar to standard smooth dies but have an additional rib along the center of the conical reducing section. The use of this rib is necessary to form a fold on the tube wall so that subsequent deformation can impart the final lobe-shaped profile to the tube. Although having an additional rib on the die has obvious advantages, the presence of this rib does make the die more difficult to fabricate.

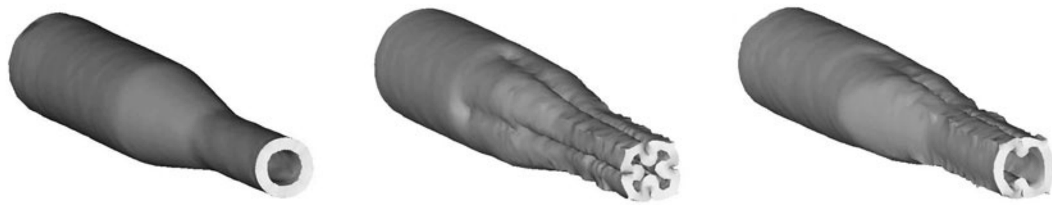


Fig. 2. Profile of the front end of the tube: *a*) circular cross section; *b*) lobe-shaped cross section; *c*) figure-eight cross section.

The maximum diameter reduction achieved on smooth dies is usually 35%, but it can reach 50% on nonferrous metals and metals with a low resistance to deformation. When dies with a rib are used for forging, the lower boundary of the allowable range of reductions of the semifinished product increases from 35 to 43%.

One important factor in optimizing the shape of the cross section of a tube before its drawing is evaluating the energy-force parameters of the forging operation on a radial forging machine. An effective approach was described in [4] for determining the forging force with allowance for the complex motion of the tool and the change in the deformation zone over time. The article also noted that the forging force decreases appreciably when the tube wall becomes unstable. This is in contrast to the case when there is no loss of stability during forging.

At the same time, engineering methods of problem-solving cannot by themselves model the deformation of semifinished products during forging in dies of different configurations. Accordingly, such methods alone also cannot determine the most efficient shape for the grip of tubes of a given size.

It is fairly difficult to shape small and thin-walled tubes on smooth dies if it is necessary to prevent the formation of folds. In such cases, it is suggested that the forging operation be performed with the use of a rod or mandrel to form the internal cavity of the semifinished product. This is the technology employed on technically obsolete rotary forging machines and pneumatic hammers [5]. For a long time, the benefits of forging on a mandrel on an AVS machine were not taken advantage of because of certain design features of the machine and the complicated trajectory of the tool. The authors are now working on a scheme for performing such forging.

The problem of optimizing the cross section of the semifinished product was solved by the finite-elements method (MFE) with the use of the application package DEFORM. This software has proven itself to be a universal set of programs that has a user-friendly interface and offers a wide range of possibilities for modeling. Theoretical studies made of transients in metal-shaping with the use of DEFORM have confirmed its effectiveness for determining the parameters of processes [6].

In modeling the forging operation, we tested three different schemes for configuring the dies of the forging machine in order to obtain grips in the form of a circle, a "lobe," and a "figure-eight." The figure-eight grip profile is obtained by combining the die configurations used to obtain circular and lobe-shaped profiles. In this case, it is necessary to use two dies with an additional rib and two smooth dies. The ribbed and smooth dies are arranged in pairs and placed opposite one another. In all three cases, we used a tubular steel 10 semifinished product with a diameter of 36 mm and a wall 3.4 mm thick. This size of semifinished product was chosen because its cross section remains stable during the forging operation.

Theoretical studies conducted using the package DEFORM made it possible to find an efficient shape for the cross section of the front end of the tubular semifinished product prior to the drawing operation. As was presumed, the thickness of the wall of the forged part is increased by an average of 30–35% when only smooth dies are used (Fig. 2*a*). Similar results have been obtained in many theoretical studies and confirmed in practice [2].

As was noted in [4], the forging force that develops when the tube wall becomes unstable is considerably lower than in the case of forging without loss of stability, i.e., forging on a "circle" (see Table 1). Here, a reduction in the thickness of the wall does not affect the strength of the forged part of the tube, since there is a simultaneous increase in the total cross-sectional area of the profile and the stiffness of the tube's cross section (Fig. 2*b*). Obviously, an increase in the cross-sectional

TABLE 1. Change in the Thickness of the Tube Wall and the Forging Force

| Profile of the front end of the tube | Average value of wall-thickness, mm | | Change in wall-thickness, % | Forging force | |
|---|---|---|---|---|---|
| | before forging | after forging | | kN | % |
| Lobe | 3.4 | 3.1 | –8.8 | 299 | 100.0 |
| Circle | 3.4 | 4.5 | 32.5 | 385 | 128.7 |
| Figure-eight | 3.4 | 3.2 | –5.8 | 402 | 134.4 |

area of the profile will require an increase in the force needed for longitudinal tension of the end of the tube, and that could have a positive effect on the conditions under which the tubular semifinished product is gripped in the drawing operation:

| **Shape of cross section** | **Tensile force on the tube, kN/%** |
|---|---|
| Figure-eight | 94.9/100.00 |
| Circle | 95.8/100.95 |
| Lobe | 99.0/104.32 |

It is inefficient to use just one pair of ribbed dies to form a figure-eight profile on the tube end because that would not reduce the forging force. Also, the strength properties of a figure-eight-shaped profile are inferior to those obtained with a lobe-shaped grip (Fig. 2c).

**Conclusion.** Studies of the forging of semifinished tubes with the formation of differently shaped cross sections confirmed the expediency of using ribbed dies to obtain a folded profile in the form of a lobe. Using a tube whose forged part has such a profile improves the preparation of the tube for drawing from the standpoint of the effect of the preparatory operations on the tube's later chemical treatment. In some cases, using such a tube also makes it possible to perform the forging operation without additional heating thanks to the reduction in the forging force that is used. Eliminating the need for additional heating will in turn undoubtedly help reduce the production cost of the finished product.

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