

Influence of Process and Billet Parameters on the Dimensional Accuracy of Hexagonal Pipes During Mandrel Drawing

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Abstract. The object of the article is hexagonal profile tubes with a round inner hole. Tubes of such configuration have wide enough application, however the way of their obtaining by drawing in profile tool is insufficiently investigated. The paper is devoted to description of creation of finite element model of plastic deformation process of pipes, the basic computational capabilities of the model are given, a number of conclusions made on the basis of modelling results are given.

1 Introduction

Metal products, providing the best ratio of economic effect from their application to the cost of production and operation, meet the modern requirements of energy and resource saving. Such products include hexagonal pipes made of materials that meet the requirements of their operation. Application of such pipes in branches of general engineering, metallurgy, nuclear engineering, heat power engineering, construction and others provides obtaining of considerable technical and economic effect [1]. The problems of determining the flow of metal when drawing hexagonal tubes on a mandrel, building a rational configuration of the working channel of the fibres, determining the pressure on the tool, shape change during profiling and deformed state are practically not investigated.

The main difference of deformation centre during drawing of hexagonal tubes with variable wall thickness along the perimeter from drawing of round tubes under otherwise identical process conditions (drawing, length of plastic zone, stresses, contact friction, etc.) is asymmetry of metal flow relative to the drawing axis. This leads to an increase in non-uniformity of deformation, the emergence of additional shifts in different directions of the contact surface and longitudinal stresses. These features are determined by the complexity of the shape of the profile and the degree of difference in the shape of the cross section before and after deformation during the pass. The measure of complexity to a certain extent is the value of the ratio of the perimeter of the profile tube to the perimeter of the equally level ring, as well as the ratio of the distances between the two most distant points of each contour with equal cross-sections. The nature of metal flow depends on the considered conditions of the process. It should be noted that the latter is determined by the general law of plastic deformation – the law of least resistance.

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A solid-volume model of the deformation centre was built, which was then interpreted in finite-element form [2] (Fig. 1). Metal hardening and contact friction (index ψ) are taken into account [3].

As shown by the analysis of the geometry of the centre and the features of the metal flow in drawing on a mandrel of pipes with variable wall thickness [4] in comparison with pipe profiling by bending the wall, there are the following main features:

1. The given form of the contact surface leads to a complex pattern of metal flow, namely to the volumetric movement of metal particles in the longitudinal, radial and transverse to the drawing axis directions and the occurrence of areas of thinning or thickening of the pipe wall.

2. The resulting difficult metal flow along the ribs of a polygonal profile, or along the hollows and protrusions of a curved profile leads to increased metal pressure on the working tool and increased contact shear stresses, which reduces tool durability and causes increased demands on the quality of metal preparation before drawing and the applied technological lubrication.

3. The kinematic and force features of the deformation centre discussed above cause an increase in the tractive force required to perform the process, which leads to a decrease in the strength reserve of the pipe front end and, as a result, leads to a decrease in the permissible drawdowns. In addition, there are increased demands on the quality of the drag hammering of the pipe front end. In turn, this can lead to the necessity to carry out multi-transition drawing.

Thus, it is necessary to analyse the deformation conditions of the process, identifying areas with unfavourable distribution of the strain intensity. This is especially important when using pipes made of hard-to-deform materials. In order to establish a picture of the features of the above parameters, let us consider sequentially: the influence of the billet dimensions on the geometry of the finished tubes, the shape change of the contact zone boundaries of the hearth and rib curvature, metal movement along the pipe faces and ribs for cases of polygonal cross-section description.

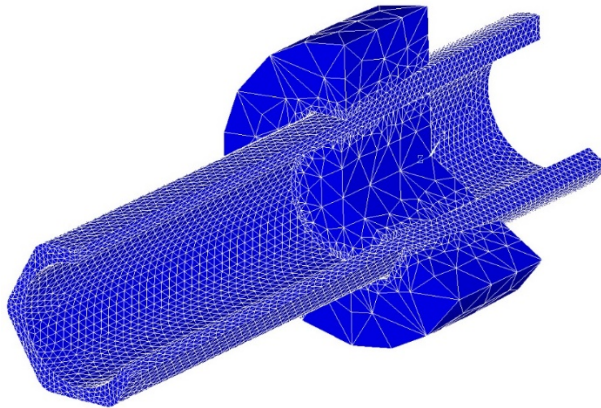


Fig. 1. Finite-element model of the deformation centre.

2 Influence of billet dimensions

At the first stage the influence of the billet on the geometry of the finished tubes and stability of the profiling process was investigated, the cross-sectional area of the tube billet was varied. As a result of modelling, it was found that changing the area of cross section within the tolerances of increased accuracy pipe billets standards does not lead to significant changes in the geometry of the finished tubes. A greater increase in area of billet leads to improvement

of profile corners filling, but causes loss of strength of tubing end coming out of the drawing. In turn, a decrease in the cross-sectional area of the billet can result in a non-filled profile (Fig. 2). Indeed, if the cross-sectional area of the tube billet is much less than the area of the outlet channel, formed by the tool (drawing and mandrel), then there is a phenomenon, which can be called "lack of metal volume" [5]. In this case there is profiling of the pipe on the outer surface (formation of a hexagonal profile with a significant value of the radii of ribs), as well as thinning of the wall in the areas on the edges of the profile in the gaps between the drawing and the mandrel. However, the inner profile zones near the ribs have no contact with the mandrel, so there is a radius that is equidistant from the outer radius on the profile rib (the wall thickness remains unchanged and close to that of the tube billet). The resulting inner profile has the form of a circle with arc-shaped rays on the profile ribs [6].

To establish the influence of the friction index on the process parameters ψ it was varied in the range from the real value determined by the practice of 0.09 to the minimum value of 0.005.

3 Contact zone boundaries and rib radii

As the points of the billet move along the drawing from the entrance to the exit, there is a contact zone of the pipe and the drawing, which becomes wider as it advances, with the lateral boundaries extending approximately in a straight line (Fig. 3) [7]. This expansion on the lateral surface is limited to areas where rib radii are formed. Calculations using the FEM model showed that the mechanical properties of the pipe material have little effect on the formation and size of the contact zone, which are determined mainly by the geometry of the contacting surfaces. However, the ability of the metal to lubricate through the friction index has some influence.

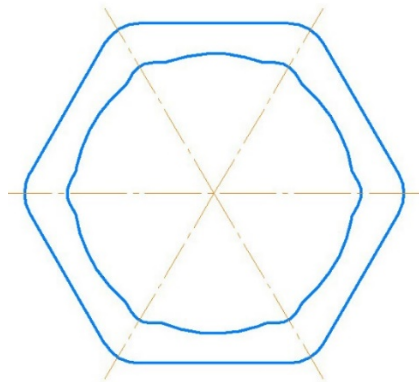


Fig. 2. Cross-section of the pipe with reduced wall thickness of the billet.

The variation of the radius of curvature of the ribs shown in Fig. 3, we can conclude that from the input to the output the radius of curvature changes from $D_3/2$ to some finite value, determined by both the conditions of deformation and the parameters of the geometry of the workpiece. As the friction index increases, the flow of metal into the corners of the drawing slows down, and the expansion of the lateral boundaries of the deformation zone also decreases.

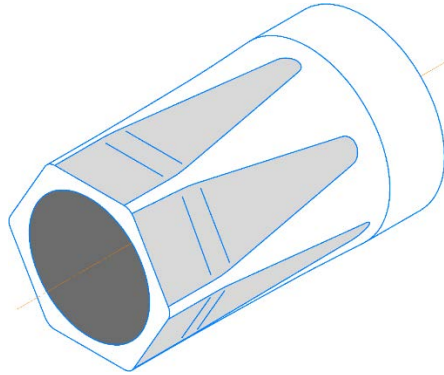


Fig. 3. Formation of the contact zone boundaries on the pipe profile faces.

The difference of radial size of the drawing in the corners of the profile and the point of maximum radius of the tube (Fig. 4) along the rib increases with the increase of friction index and is somewhat different for steel 10 and titanium BT1-0 (Fig. 5).

4 Metal displacement along the faces

The displacement of the material on the outer surface of the tube along the faces from the entrance to the deformation centre was considered. It was found that the instantaneous values of this parameter are distributed unevenly. The maxima are located in the middle of the faces and are somewhat displaced toward the exit, while the displacement decreases near the rear boundary of the centre.

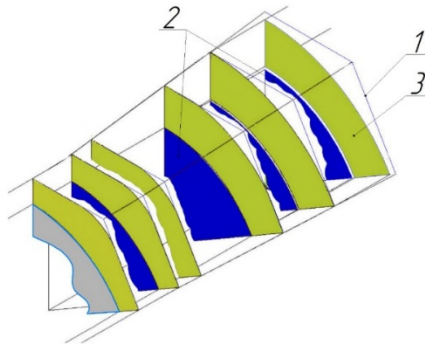


Fig. 4. Change of profile rib radius along the deformation centre. (1 - drawing contour, 2 - mandrel position, 3 - tube shaping).

5 The deformed state of the metal

The above considered features of the shape change and flow of the metal determine the deformed state, which was evaluated by the intensity of deformation ε_i (Fig. 6). These values are different on the outer and inner surfaces of the pipe. In general, the values of strain intensity on the inner surface are greater than those on the outer surface. Regarding these differences, on the outer surface, the maximums are located in the middle of the faces and the minimums along the ribs of the profile. On the inner surface, the picture is different. Thus, the maximums are located in the middle of the face. There is also an absolute maximum of the

strain intensity. In turn, the minimum value takes place in the sections corresponding to the outer faces.

Depending on the material grade, it was found [8] that for alloy VT1-0 all values of strain intensity are less than for steel 10, which has lower mechanical properties. At the same time, the contact friction index has little effect on the deformed state. Note that since for the considered case of profiling the finished tube with an outer hexagon is quite close to the outline of a round tube, the coefficient of non-uniformity of strain intensity does not exceed the value $K_H = \varepsilon_i^{max} / \varepsilon_i^{min} \leq 1,41$.

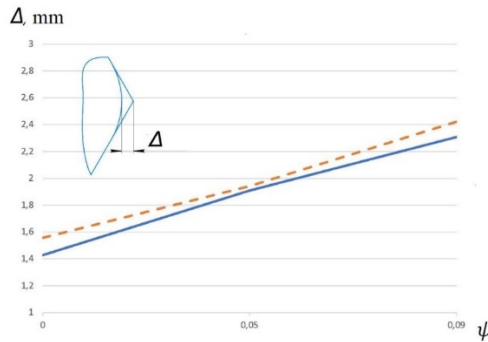


Fig. 5. Dependence of unfilled corners of the profile Δ on friction index. ψ : solid line - steel 10, dotted line - titanium VT1-0.

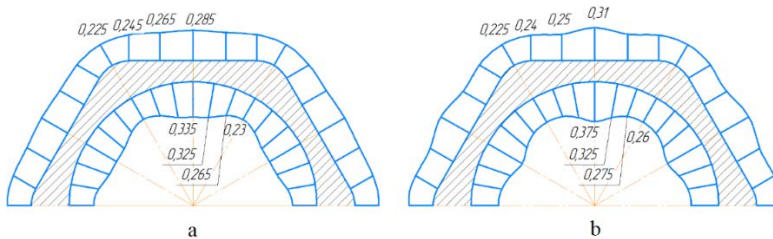


Fig. 6. Distribution of strain intensity in the outlet section of the pipe. Materials: a - alloy VT1-0, b - steel 10; friction index $\psi=0,09$.

6 Contact pressure of the metal on the working tool

Contact pressure on the surfaces of the working tool determines many characteristics of the tool itself, as well as important indicators of the drawing process. Contact pressure in the centre of deformation should be found both for the drawing and for the mandrel. It should be noted that the contact pressure during drawing on TPTS mandrel has not been studied so far.

This indicator should be determined for the following reasons: on the basis of the calculation of contact pressure it is possible to select the materials of fibres and mandrels, it is possible to determine the durability of fibres and mandrels and the selection of technological lubricants, it is necessary to find the axial force acting on the mandrel.

As for the first and the second reasons, since the size range of the TSTS is from 5 to 150 mm on the outer surface, it is impossible to cover the whole range of pipes with the help of tungsten carbide tools and it is necessary to use steel tools. At the same time, it is necessary to select a steel grade, determine the choice of lubricant type and technology of underlaying and lubricating layers [9].

Determination of the axial force acting on the mandrel and evaluation of the mandrel bar strength in this regard is based on the procedure of calculating and summing up the normal pressure forces and finding the tangential friction forces across the mandrel surface.

Using the models developed above and the finite element method, it is possible to find the contact pressure in the deformation centre. The maximum contact pressure occurs at the beginning of the contact surface. Then, as the contact surface develops, the pressure extends over a larger area, and at the same time, the pressure magnitude decreases. For different materials, the nature of the pressure is similar, but the magnitude of the pressure is different.

For titanium VT1-0 in comparison with steel 10 the pressure value is higher (Fig. 7), but the relative value of the pressure peak is in both cases in relative values of about $2.5 \sigma_{0.2}$. On the mandrel the contact pressure curve has more gradual character. The onset of the pressure peak is somewhat later than on the mandrel, and the relative pressure value is maintained.

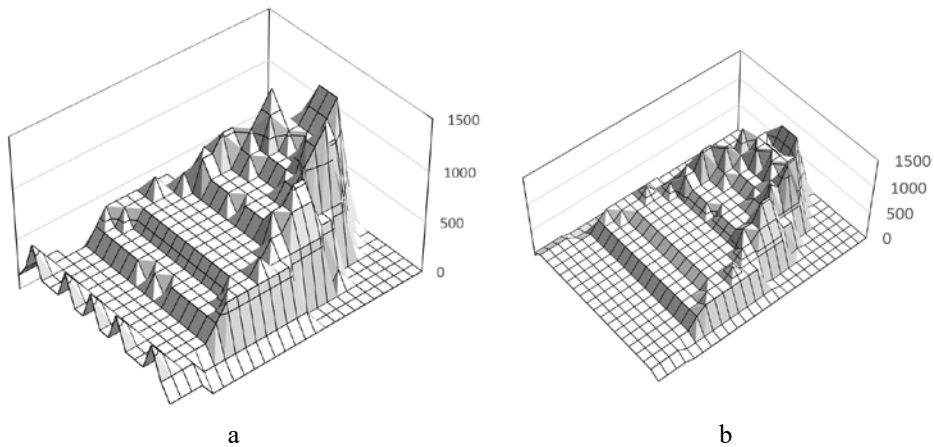


Fig. 7. Distribution of contact pressure (MPa) over the surface of the deformation zone: a - drawing, b - mandrel. Pipe material - Titanium VT1-0, $\psi=0,09$.

7 Conclusions

1. It is established that the choice of the outer diameter and wall thickness of the billet are within rather narrow limits. Thus, increasing the billet cross-sectional area somewhat improves the geometry of the finished tubes, but is limited by the strength of the front end of the tube, on the other hand, reducing the cross-sectional area of the billet leads to incomplete filling of the profile.

2. The value of radial displacement is maximal in the middle of the face of a polyhedral profile. At the same time, the ratio of radial and longitudinal displacements is such that even if the outer diameter of the billet exceeds the furthest from the pipe axis point of the profile on the profile ribs there is a zone of out-of-contact deformation, which decreases in width and height as the pipe moves from the entrance into the deformation centre to the exit.

3. The reduction of the contact friction index improves the filling of the profile corners only up to a certain limit and depends little on the material grade. Intensity of deformation has maximum values on inner surface of a tube in the middle of an edge and minimum values on profile ribs, and on outer surface of a tube maximums are located in the middle of an edge and on profile ribs, and for material having increased mechanical properties all intensity values are somewhat lower.

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