Analysis of the influence of the geometry of the input part of the matrix on the formation of the edge part of the cylindrical bill

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Abstract. The formation of an uneven geometry of the end part of cylindrical products is quite common after the implementation of drawing of sheet blanks. It occurs due to the imbalanced orientation of the crystallographic structure of the material, that is, due to the anisotropy of the mechanical properties. As different elements of the sheet bill have different speed of movement relative to the tool during the drawing, so-called scallops, or protrusions, appear. This causes a problem during the production, since it takes additional time and resources to bring the geometry of the products to the norm. Therefore, the actual task is to minimize this phenomenon. The article discusses an approach to eliminating or minimizing scallop formation by means of scientifically grounded selection of the geometry of the input part of the matrix. The influence of geometry parameters on the uneven geometry of products and their stress state is described.

1. Introduction

In stamping production, namely in sheet stamping technologies and drawing processes, there is always a strong issue of minimizing the distortion of the geometry of products arising in the process of forming [1-4]. The main factor leading to the formation of an uneven geometry of the edge of the cylindrical shell is the imbalance of the mechanical properties, leading to the difference in the speeds of displacements of different elements of the bill relative to the punch and matrix during the drawing process [5-8]. One of the ways to eliminate scallop formation is to prepare the geometry of the bill, that is, to obtain the profile geometry [9-13]. But this method, due to certain production circumstances, is not always applicable. In this regard, the task was to minimize scallop formation on the shell. In this paper, it is proposed to use matrices with a complex geometry of the input part, which will allow redistributing the speeds of movement of different elements of the bill, and thus a positive effect will be achieved, which consists in obtaining a more balanced geometry of the end part of the resulting shells.

2. Materials and methods

The DEFORM software package was used to perform the research. The research was carried out using the finite element method. The modeling of the drawing process to obtain the mentioned products was performed using the basic provisions of the theory of plasticity of an elastoplastic, incompressible, hardening material. Steel 20 was used as the bill material. It was considered that the process is carried
out in a cold state with a corresponding model of bill’s material behavior. The deformation rate equaled 50 mm/s. The bill diameter was equal to 50 mm. The bill thickness was 1 mm. The rheological model of the bill is elastoplastic. The size of the final elements of the workpiece is 0.3 ... 0.6 mm. The punch diameter was $D_{\text{punch}} = 37$ mm. Matrix diameter equaled $D_{\text{matrix}} = 40$ mm. The bill diameter varied in the range of $D_{\text{blank}} = 50...60$ mm. Fig. 1 shows a diagram of the process. Fig. 2 shows a sketch of the matrix.

![Figure 1. Process scheme](image1.png)

![Figure 2. Matrix](image2.png)
3. Results and Discussion

Fig. 2 shows a sketch of the matrix with the proposed profile of the input part, which is a set of different radii, the values of which are calculated from the condition of equality of the speeds of movement of the edge elements of the bill. To do this, we need to determine the profile of the bill, which allows getting the product without scallops [3, 4, 6]. Using expressions for estimating the speeds of displacements of points of the bill in the radial direction [3, 4, 6], the time required to move the edge elements of the bill in the areas of formation of protrusions and depressions at the end of the cylindrical part of the product is set. In the future, using the resulting expression, it is possible to derive an expression for calculating the minimum radius of the profile bill

\[ R_x = R_m[1 + (2 + f_f)((R_{\text{max}}/R_{\text{min}})^{2f_f} - 1)/(2 + f_v)]^{1/2 + f_f}. \]  

(1)

Here \( R_{\text{max}} \) and \( R_{\text{min}} \) are respectively the maximum and minimum radii of the profile bill, \( f_f \) and \( f_v \) are the parameters associated with the anisotropy coefficients.

Based on the expression (1), the average radius of the profile bill can be calculated by the expression

\[ R_K = (R_{\text{max}} + R_{\text{min}})/2 + (R_{\text{max}} - R_{\text{min}})\cos 40/2. \]  

(2)

A matrix with a profile geometry must be created in such a way that in the direction of the greatest formation of protrusions at the end of the product, the radius of the input part of the matrix should be maximum and its value should equal 10 ... 25 values of the thickness of the bill, and in the direction of formation of depressions, it should equal the minimum permissible value according to the recommendations for the drawing process. According to expression (2), the average values of the radius of the input part of the matrix are determined by the expression

\[ R = R_2 - 0.876(R_{\text{max}} - R_{\text{min}}) - (R_{\text{max}} - R_{\text{min}})\cos 40 \]  

(3)

The DEFORM software package was used to simulate different cases. The calculations were carried out for a smooth matrix die, without the input part, for matrix dies with a profile input, for which the maximum input radius varied within \( R_2 = 10...30 \text{mm} \) with variation intervals of 5 mm.

Fig. 3 shows the diagrams of the process before the drawing. Fig. 4 shows sketches of the parts obtained after drawing for different variants of the geometry of the input part.

**Figure 3.** Schemes of the process before drawing: 1 – matrix with a smooth surface; 2 – with a profiled surface

**Figure 4.** Sketches of the obtained parts after drawing (\( R_1 = 7 \text{mm} \)): 1 – smooth matrix die; 2 – \( R_3 = 30 \text{mm} \)
Figure 4 shows that in our case, the use of a matrix with a special geometry allows us to obtain an even product. In the case of an isotropic material of the bill, due to the equality of the speeds of movement of the edge elements of the bill, an even end of the product is obtained, without the formation of scallops. With explicit anisotropy, situations with explicit scalloping are realized. This can be explained by the fact that at the same speeds of movement of the elements of the parts in the radial direction for an isotropic bill with a die with a profile input part, these elements have a different movement path in the direction of material movement along the perimeter of the matrix die. In view of this, as a result, the edges of the bill at the final moment of deformation made a different path. Unevenness is formed. Summarizing the data, we can say that the use of dies with a complex and uneven profile of the input part will make it possible to control the speed of movement of the edge elements of the bills, which means that it will allow obtaining cylindrical products both with scallops of a given geometry, and without scallops. By controlling the speed of movement of the elements of the edge parts of the product, you can achieve a smoother end part of the product when using an anisotropic bill. Later we needed to assess the influence of the geometry parameters of the input part of the matrix on the bill height. Studies on the influence of the stretch ratio on the height of the scallops with a fixed shape of the input part of the die were carried out. Based on the results of modeling of the process under study, the dependences of the elongation ratio and geometry of the input part on the minimum (along the depression at the end) and maximum (along the protrusion) height of the product were obtained. Fig. 5 and 6 show the obtained dependences.

**Figure 5.** Dependence of the drawing coefficient and the geometry of the input part and the minimum height of the product ($R_1 = 7$ mm): 1 – $R_2 = 30$ mm; 2 – $R_2 = 20$ mm; 3 – $R_2 = 15$ mm; 4 – smooth matrix die

**Figure 6.** Dependence of the drawing coefficient and the geometry of the input part and the maximum height of the product ($R_1 = 7$ mm): 1 – $R_2 = 30$ mm; 2 – $R_2 = 20$ mm; 3 – $R_2 = 15$ mm; 4 – smooth die
Analysis of the dependencies shown in fig. 5 and fig. 6 allows us to conclude that the shape of the input part of the die affects the height of the products being formed, and in particular the heights along the protrusions and depressions on the edge part of the bill. In particular, an increase in the difference between the radii on the die $R_2/R_1$ leads to a change in the height along the depressions by 10% for drawing coefficient of 0.65. For drawing coefficient of 0.8 this difference is 6%. For drawing coefficient of 0.65 the increase in the difference between the radii on the die $R_2/R_1$ leads to a change in the height along the protrusions by 7% and by 11% for drawing coefficient of 0.8.

It has been established that the use of dies with a profile entry in general should have a positive effect on the geometry of the end part of the product. Proper selection of the geometric parameters of the profile of the input section of the matrix minimizes the influence of anisotropic properties of the bill on the formation of uneven geometry of products. For the practical application of the results, dependences were obtained that allow calculating the values of $R_{\text{max}}$ and $R_{\text{min}}$. Knowing the height of the product from the bottom to the depressions $h_{\text{min}}$ and protrusions $h_{\text{max}}$ on the edge part using expressions

$$h_{\text{min}} = 1.98 R_{\text{min}} - 59.79; \quad h_{\text{max}} = 1.58 R_{\text{min}} - 47.79.$$ 

Knowing the height of the bill, it is possible to determine the values of $R_{\text{max}}$ and $R_{\text{min}}$, and after their substitution into expression (8), a rational value of the input radius of the die is found, which makes it possible to minimize the scallop formation.

4. Conclusion

Determined that formation of unevenness of the end elements of the product during the drawing of anisotropic materials is influenced by the uneven speed of movement of the edge elements of the die due to the imbalance of the mechanical properties. It was found that the use of a deforming tool with a special input profile, which compensates for the uneven velocities of the edge elements of the bill, makes it possible to reduce scallop formation. The scientifically grounded selection of the geometric characteristics of the input profile of the matrix die, carried out during the modeling, made it possible to identify rational characteristics that ensure minimal scallop formation.

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