DESIGN OF STAMPING DRAWING TECHNOLOGY FROM THIN SHEET

[1]Radek ČADA, [1]Tomáš PEKTOR

[1]VSB - Technical University of Ostrava, Ostrava, Czech Republic, EU, radek.cada@vsb.cz

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Abstract

The paper deals with the design of the technology for the production of the cover stamping to achieve the minimum cost of one piece of the produced component. By calculation, the minimum values of the radius of curvature of the edge of the draw die and the edge of the draw punch were determined to eliminate the calibration operation. The shape and dimensions of the blank for the cover stamping were determined by several methods and then compared. Simulations of the drawing process allowed the locations with the greatest thinning to be analyzed and the drawability of the stamping from each alternative of the blank shape to be verified. The results of the simulations showed the highest suitability of the blank determined by the Autodesk Inventor program and also by the BSE module in Dynaform. The simulation results further demonstrated the necessity to increase the radii of curvature of the drawing edge of both the draw die and the draw punch to a value of 4 mm, which allows the fabrication of a defect-free cover stamping without the need for subsequent calibration. The use of the simulation program in the technological preparation phase of production allowed one to optimise the drawing process by a suitable design of the shape of the blank and also allowed one to design a change in the shape of the stamping which eliminated the formation of cracks at its bottom during drawing.

Keywords: Drawing, stamping, technology, sheet, simulation

1. INTRODUCTION

Plate forming technology has multiple applications in manufacturing due to minimal waste and low production costs, but only under the assumption of low scrap in the mills. The cause of rejects is often the lack of technology of the manufactured parts, which exceeds the limits of formability of the material or incorrectly chosen shapes of the blanks.

For the production of deep- or complex- shaped stampings, it is necessary to choose a deep-drawing steel with good formability [1]. Another important property of the material is its weldability and post-weld properties in the heat-affected zone [2]. The most commonly used material in the Czech Republic is DC04 killed steel, which is produced by continuous casting and hot rolling [3]. The mechanical properties of sheet metal can be increased in some applications, for example, by the unconventional forming method DRECE (Dual Rolls Equal Channel Extrusion) [4-6].

When designing a drawing tool, it is advisable to verify its functionality by simulating the drawing process before manufacturing. It is necessary to design the appropriate shape of the blank, dimensions, and material of the blank and to verify the suitability of the designed shape of the components for the sheet metal drawing production method. The method of deformation networks [7] can be used to analyze material flow in the drawing process. In some cases, after selecting a suitable production method, it is necessary to modify the shape or even the properties of the component so that it is easier to produce by the selected production method while maintaining the required performance characteristics. In the subsequent manufacturing process, a properly designed maintenance organisation [8,9] and the monitoring and prevention of defects [10] are important. The achievement of maximum productivity while eliminating waste can be achieved, for example, by using the Value Stream Mapping Method [11] and the good design of the distribution warehouse [12].

2. COVER STAMPING

The initial dimensions of the 1 mm thick sheet metal cover stamping are shown in **Figure 1**. A stamping model was created in Autodesk Inventor based on the fabrication drawing of the cover supplied by the client (**Figure 2**).

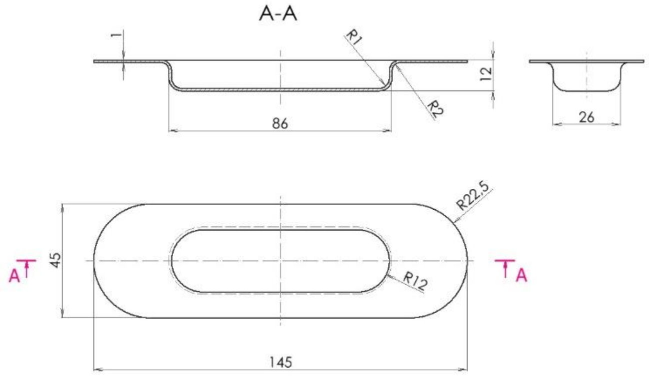

Figure 1 Dimensions of the cover stamping

Figure 2 Model of the cover stamping

3. DESIGN OF THE TECHNOLOGICAL PROCEDURE FOR THE PRODUCTION OF THE STAMPING

Due to the small radii of curvature both between the flange and the vertical wall of the stamping, and between the vertical wall of the stamping and the bottom of the stamping, it is advisable to check at the outset whether these requirements make it necessary to produce a given cover stamping in two operations, drawing, and calibration. Therefore, the values of the minimum radii of the die-drawing edge and the punch-drawing edge were calculated.

According to CSN 22 7303 "Drawing of Hollow Square Stampings", the optimum size of the radius of the die drawing edge can be calculated from equation (1):

$$r_{\text{opt}} = (6 \div 10) \cdot t \qquad (1)$$

where:

t - thickness of sheet metal (mm).

Higher values of the radii of curvature of the die drawing edge cause that a larger area of the sheet metal is not clamped between the parts of the tool, thus there is a greater risk of secondary wrinkling (wrinkling of the stamping walls). Small values of the radii of the die drawing edge increase the drawing force and also increase the risk of bottoming out due to higher radial stresses in the stamping.

The minimum radius of the die drawing edge can be calculated according to equation (2):

$$r_{1\min} = 0{,}05 \cdot [50 + (D - d)] \cdot \sqrt{t} \qquad (2)$$

where:

D - size of the drawing die (mm),

d - size of the drawing punch (mm),

t - thickness of sheet metal (mm).

By substituting the values for the solved cover stamping in equation (2), the minimum radius of the die drawing edge r_{1min} = 2.55 mm was found.

The size of the drawing gap in the longitudinal parts of the drawing tool (according to CSN 22 7303) can be calculated from equation (3):

$$t_{\mathrm{m}} = (1.15 \div 1.30) \cdot t \tag{3}$$

Since the designed cover stamping is dimensionally small, the coefficient value of 1.15 was chosen in equation (3), that is, the resulting value of the size of the drawing gap in the longitudinal parts of the drawing tool t_m = 1,15 mm.

The size of the drawing gap in the corner parts of the drawing tool (according to CSN 22 7303) can be calculated from equation (4):

$$t_{\mathrm{mr}} = 1.30 \cdot t \tag{4}$$

For the production of a cover from 1 mm thick sheet metal, the size of the drawing gap in the corner parts of the drawing tool must be used t_{mr} = 1,30 mm. The minimum radius of curvature of the punch drawing edge was determined from the exact drawn condition at the corner of the drawing tool: r_2 = 1,83 mm. From the calculated values of the minimum radii of the drawing edge of the drawing tool and the punch drawing edge, it is clear that the values of the radii on the cover stamping display (**Figure 1**) cannot be achieved directly by drawing, but only by a combination of drawing and subsequent calibration. Since drawing and subsequent calibration are costly due to the need to produce two forming tools, a modification of the cowl extrusion shape was designed to match the original design of the extrusion shape as closely as possible, but to be produced with only one forming tool, i.e. one drawing operation.

4. CREATION OF THE BLANK MODELS FOR COVER STAMPING DRAWING

After importing the final stamping model (**Figure 2**) with trimming allowances, a cut shape was generated using the BSE module in Dynaform (**Figure 3**).

For the manufacture of the cover stamping, DC04 (11 305.21) deep-drawing steel with a thickness of 1 mm was chosen.

Subsequently, a finite element mesh was generated on the blank model according to the contour of the blank forming the boundary line, which formed the shell of the blank model.

The determination of the shape and size of the blank was carried out using other methods - the method according to CSN 22 7303, where a technological allowance for the shape sharpening of 5 mm was added, the method of cuts, method using the Autodesk Inventor program, and method using the maximum shear stress trajectories. A comparison of all the alternatives of the blank shapes to draw the cover stamping is shown in **Figure 3**.

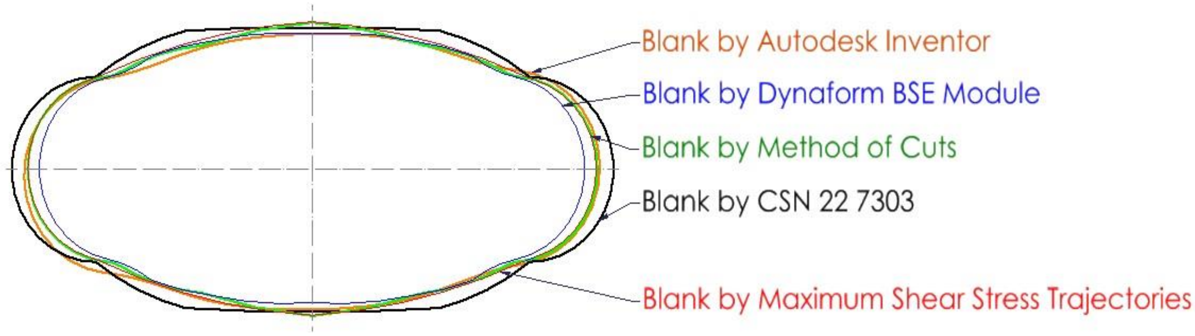

Figure 3 Comparison of blank shapes for drawing the cover stamping determined by different methods

5. NUMERICAL SIMULATION OF THE FORMING PROCESS

5.1. Modifying blank models in Dynaform

The blank model was created in the Autodesk Inventor program as an igs file and then imported into Dynaform. Each model was created from lines and surfaces only; the element mesh had to be created in the "Preprocess" module in the "Element" tab. The size of the elements was chosen to be 1.5 mm. Excess surfaces and lines were removed to create a surface of zero thickness. Finally, a check of the direction of the element normals ("Auto plate normal"), a check of the overlapping elements ("Overlap element") and the continuity of the mesh ("Display model boundary") was performed on the created elements. All blanks were adjusted in this way.

5.2. Calculation of the required holding force for the alternatives of the blank shape

Because each blank has different shapes and dimensions, the area of contact between the blankholder and the blank (called the effective area of the blankholder) is different in each case.

The required holding force was determined from the following equation:

$$F_p = p_p \cdot S_p \quad (5)$$

where:

p_p - specific holding pressure (mm),

S_p - the effective area of the blankholder (mm^2).

The specific pressure of the blankholder was chosen to be 2 MPa and the effective area of the blankholder was calculated using Autodesk Inventor.

5.3. Specification of simulation conditions and performing simulations

To simulate the drawing process, tools were created, and the following were defined: material of the blanks, shape and dimension of the blank, tool path, force of the blankholder, speed of the draw punch, etc. Setting and defining all the boundary conditions of the forming process was done in the Tools menu in the Dynaform menu bar. In order to compare the alternatives of the blanks and also to check the design of the working parts of the forming tool for the drawing of the cover stamping, simulations of the flat forming process were carried out in Dynaform. Since the objective of the analysis was to check the design of the working parts of the forming tool to draw the cover stamping, the mechanical and plastic properties of the formed material (see chapter 4) were taken from the Dynaform material library. The following input parameters were set for the simulations: finite element mesh element size 0.5 mm, shear friction coefficient 0.13, pull-out temperature 20 °C, initial sheet thickness 1 mm. In critical areas of the stamping where large plastic deformations exist, Dynaform automatically performed mesh thickening during the calculation. Simulations of the drawing process with the use of different blank shape alternatives (**Figure 3**) were performed, and then the individual analyzes were displayed in the post-processor (see chapter 6).

6. SIMULATION RESULTS

After simulations of the forming process of the cover stamping from the different alternatives of the blank shape in Dynaform software, individual analyzes were carried out, from which the following were selected as examples: analysis of the drawability of the cover stamping using the forming limit diagram of the sheet used (**Figure 4**), analysis of normal strain, analysis of material thickness after drawing (**Figure 5**), analysis of sheet thinning and analysis of the edge movement of the blank during drawing (**Figure 6**). The analyzes show that the maximum strain values are at two opposite rounded locations in the curvature between the bottom and the vertical wall of the stamping. The thinning of the sheet metal is also greatest at these locations.

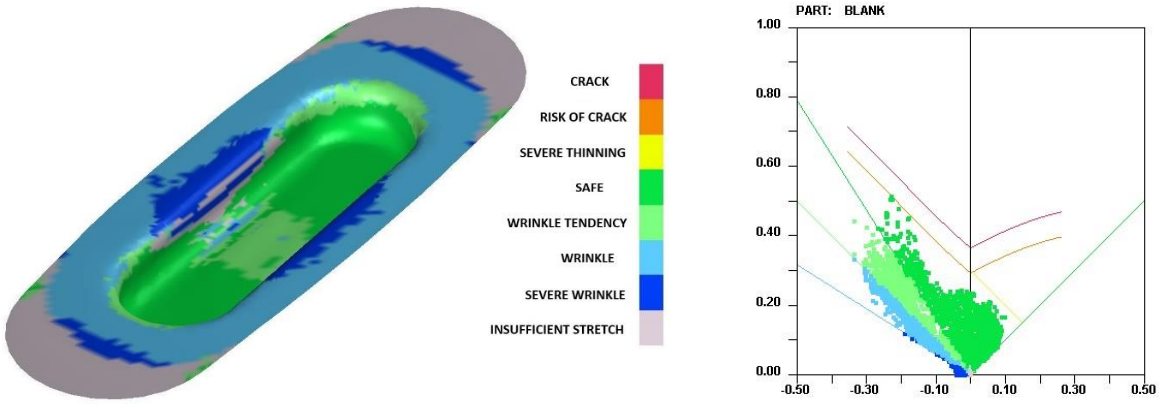

Figure 4 Analysis of the drawability of DC04 low carbon steel cover stamping using the sheet forming limit diagram (blank by Autodesk Inventor, 3 mm draw die and also draw punch curvature)

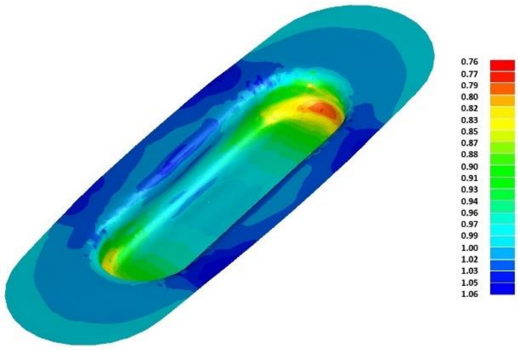

Figure 5 Analysis of the thickness of the material (mm) after drawing the cover stamping (blank by Autodesk Inventor, 3 mm draw die and also draw punch curvature)

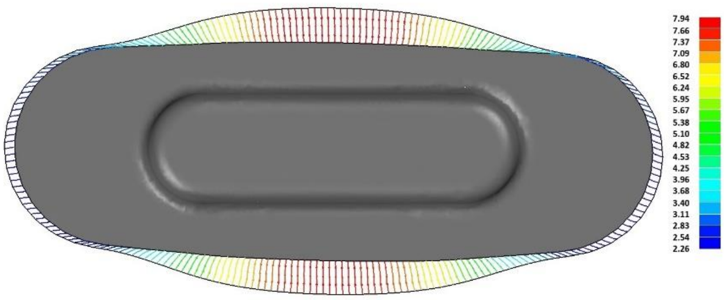

Figure 6 Analysis of the movement of the blank edge (mm) during the drawing of the cover stamping (blank by Autodesk Inventor, 3 mm draw die and also draw punch curvature)

When using the radii of curvature of the drawbar and the drawbar edge as originally requested by the client (**Figure 1**), cracking occurs when using all alternatives to the blank shape. Therefore, the cover would have to be produced in two operations, drawing and calibration. The production of the forming tool for the calibration operation would be costly and the production of the cover stamping would be more time consuming. For these reasons, modifications were made to the drawing tool models to increase the radius of curvature of the drawing edge of the draw die and later the radius of curvature of the drawing edge of the draw punch. The curvature radii of the draw die r_1 = 2 mm and the draw punch r_2 = 2 mm were used successively, then r_1 = 3 mm and r_2 = 2 mm and finally r_1 = 3 mm and r_2 = 3 mm. Simulations of the cover stamping process showed a reduction of the critical failure area with increasing values of the radii of curvature of the drawing edges. The last alternative with both drawing edge radii of 3 mm no longer showed the development of failure and is therefore a suitable design for production by drawing without a subsequent calibration operation.

7. CONCLUSIONS

The cover stamping production technology was designed to achieve the minimum cost of one piece of the manufactured component. The minimum values of the radius of curvature of the drawing edge of the draw die and the drawing edge of the draw punch were determined by calculation in order to eliminate the calibration operation. The shape and dimensions of the blank for the cover stamping were determined by several methods (the method according to CSN 22 7303, the cut method, the method using maximum shear stress trajectories, the method using the Autodesk Inventor program, and the method using the BSE module in Dynaform software) and then compared. Simulations of the drawing process allowed to analyse the locations with the greatest thinning and to verificate the drawability of the stamping from the different alternatives of the blank shape. The results of the simulations showed the highest suitability of the blank determined by the Autodesk Inventor program and also by the BSE module in Dynaform and at the same time the lower suitability of the blank determined by the method according to CSN 22 7303. Therefore, the method of generating the shear shape from the 3D model of the stamping in the simulation program can be recommended to design the shape and size of the blank to draw stampings of similar shape. The simulation results further demonstrated the necessity to increase the radii of curvature of the drawing edge of both the draw die and the draw punch to a value of 3 mm, which allows the fabrication of a defect-free cover stamping without the need for subsequent calibration. The use of the simulation program in the technological preparation phase of production allowed one to optimise the drawing process by a suitable design of the shape of the blank and also allowed one to design a change in the shape of the stamping which eliminated the formation of cracks at its bottom during drawing.

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