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Forming containers for PCM materials using a hydrotechnical method with an elastomer

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In this work, the authors present the method of forming by oil exerting pressure on the elastic punch forming the shape of a container for phase change material (PCM). Thanks to the use of two elastomer plates with a hardness of 65 and 80 Shore, the obtained part has mapped stiffeners in the middle and the appropriate depth of the bowl. This method is not widespread due to the precise design ensuring tightness of the load system of the formed blank. By reducing the tool costs, this method is used in particular in the case of unit production of prototype parts or small production series. The authors carried out tests of mechanical properties of the material, numerical analysis of feasibility with the FEM, real (workshop) trials after previous optimization by trial and error through structural changes of the tool. This allowed to obtain the best material drawing parameters for given boundary conditions. The research allowed to eliminate significant stresses and thinning in finished parts and corners of PCM containers.

KEYWORDS: *stamping, forming, elastic punch, rubber forming*

Introduction

Stamping processes with tools using elastomeric punches, especially rubber ones, are used primarily in unit and small-lot production. Complex shapes of manufactured products usually require expensive and specialized equipment. The advantage of using a flexible stamp is that a rigid die (steel or other material) is sufficient to make the stamping on the press, while the role of the stamp is played by a rubber or elastomeric spacer that adapts to the assumed shape. This allows to reduce tool costs by half and reduce the time to manufacture shaping elements.

Forming processing of sheets with the use of an elastic punch, also known as the universal punch method, offers many different forming possibilities. Flexible stamping dies supplement the forming methods with a steel rigid punch (or rigid die). The forming material can be rubber, elastomer, liquid (water or oil) or simultaneously elastomer and forming liquid. The use of hydrotechnical plastic forming (with the simultaneous use of an elastomer diaphragm and oil) is limited to forming bowl-type elements, while the method of pressing with the elastomer alone has no major restrictions. It should be mentioned that elastomer (especially rubber) can be used as an auxiliary element in the shaping process by other methods, e.g. as a pressure or filler preventing sheet cracking and folding. The main advantage of all elastomer molding methods is making the machining process independent of sheet thickness tolerance. It is also possible to shape sheets of variable thickness, so-called tailored blank method [7].

Types of flexible punches

Own work carried out on stamping with flexible stamp confirmed that rubber used as a stamp or universal matrix can be natural or synthetic. Its recommended strength properties are as follows: Shore hardness - from 60HA to 95HA, tensile strength - from 6 to 20 MPa, acceptable elongation - from 350 to 650%. The amount of unit pressure in the rubber shaping process is selected depending on the material grade, sheet thickness and deformation factor (fig. 1). This value, as a function of deformation, also depends on the grade and hardness of the rubber.

Fig. 1. Relation of unit pressure of rubber during elastic stamping as a function of stamp stroke (displacement) and deformation factor

When forming cylindrical parts, rubber pressures should be between 30 and 60 MPa. The thickness H of the rubber cushion depends on the thickness of the shaped objects h :

$$H > 50\sqrt{h}$$

The cushion, in the form of an elastomer or rubber, may consist of several individual layers, with a total thickness less than 50 mm. The best effects of rubber pressing are obtained when forming parts that meet the geometric condition:

$$l > 70g$$

where: l - the smallest length of the formed part, g - sheet thickness (own research).

Elastomer molding creates extremely favorable flow conditions for the material, especially when deep drawn and using a steel die and flexible punch. For this reason, the most commonly used are concave dies, in which the rubber acts as a flexible punch.

Modeling of the pressing process by the finite element method

In order to verify the presented forming method, the displacement values for the tested element were checked - using the finite element method (FEM) (fig. 2).

In order to assess the possibilities of making the tank with the use of a flexible stamp method, simulation of pressing with the use of FEM was carried out. A model was adopted, in which a flexible tool exerts pressure on elastic-plastic material. Numerical analysis was performed in the Pam-Stamp 2G software [6, 9]. Several material models and a dozen or so geometrical models of the tank were analyzed. The analysis used surface-type elements, three- and four-node, based on the Belytschki-Tsaya model, based on homogeneous, coherent and reduced integration. The level of FEM mesh density was selected according to the criterion of the minimum value of matrix or punch radius [2]. The FEM model developed for forming with a flexible punch is shown in fig. 3.

In the forming operation - for both closing and pressing - the function of adjusting the mesh density level to the current local degree of material deformation was activated [1]. In practice, this saves time and, at the same time, the necessary accuracy of calculations by predicting the deformation caused by the movement of the punch.

The main difficulty of the FEM numerical simulation was the introduction of the elastomer material model, from which the punch was made. The adopted assumptions about the scope of Young's modulus and Poisson's number allowed to build a model with linear characteristics, which, however, turned out to be too simplistic. To more accurately describe the analyzed process, the Mooney-Rivlin solid model was used, in which material constants are determined by matching predicted stresses to equations from experimental data. The recommended material tests are: uniaxial stretching and compression, shear and planar compression [5].

Fig. 2. Displacement values determined by FEM (vector)

Fig. 3. FEM model for forming a part of the tank with a flexible punch

Fig. 4. Tank panels model obtained as a result of finite element molding simulation

Fig. 5. Main deformations - tested element

In order to select the material for the tool, a compression test of elastomer punches made of available commercial material of various thickness and hardness on the Shore scale was conducted: 70HA, 80HA, 90HA. Ultimately, it was decided to use an elastomer sheet with 80HA hardness. The possibility of forming parts with a selected method was confirmed by numerical simulation (fig. 4) [10].

A map of stresses generated during the pressing process was also obtained. The maximum stress value is 800 MPa. Fig. 5 shows the main deformations obtained at the simulation stage.

There are several ways to mold with a flexible punch. One of them is pressing in two stroke of the slider, i.e. first pressing with the elastomer plate only (incomplete initial pressing), and then pressing by adding an additional flexible plate to the blank to obtain the final shape. Division of molding into stages allows to increase the tool life. Usually, rubber or elastomer spacers with a hardness of 40÷50 by Shore are used for the finishing molding process. The durability of such flexible elements is at the level of 2000÷5000 pieces.

A limitation in the use of the flexible stamping method is the formation of curves with small radii - due to the high concentration of surface pressures in strictly defined small areas. In this case, obtaining the required geometry requires the introduction of a finishing (calibrating) part operation.

Practical pressing tests

In order to verify the results obtained in the computer simulation, practical tests were carried out on pressing the tank panels. Blanks made of 1.4301 steel with a thickness of $g = 0.5$ mm were used [3, 4]. The die shown in fig. 6 was designed and manufactured.

The produced model is shown in fig. 7. In the process of pressing with a flexible stamp, a product with geometry that reproduces the assumed CAD model was obtained. Accurate dimensions and shape of embossing were obtained. Sheet metal folds on free surfaces outside the contour of the object [8]. The tests have shown that the occurrence of folds can be reduced using blanks with dimensions appropriately enlarged in relation to the dimensions of the product and by cutting the corners of the blanks. As a result of the pressing process, a product with satisfactory surface condition was obtained.

Fig. 6. Die for forming parts with an elastomer tool - view of the die on a hydraulic press

Fig. 7. Tank panel made by flexible stamping

Conclusions

The method of forming products with a steel stamp is more advantageous compared to forming with an elastic stamp due to the tool's durability and the use of high material pressure, which allows to avoid creasing the material on the edges of shaped objects. However, forming with a steel punch is much more expensive, because the tool is more complicated and gas springs need to be used, which significantly increases the cost of the tool (by approximately 50% compared to the tool with an elastomeric punch).

The method of forming with a rubber punch is less efficient and has a shorter tool life, which must be replaced more often. In this method, however, the tool design process is simpler and shorter, which reduces the costs of its implementation. As demonstrated by numerical analysis and practical research, elastomer molding provides the right way to shape the extrusion, therefore, this method is generally more cost-effective and guarantees good product shape at the prototype or small batch stage.

Comparing the molding methods with a rigid matrix and flexible punch, it should be noted that in the latter method, much higher deformation coefficient can be obtained. The conducted tests showed that - taking into account the size of the formed part, sheet thickness and material (chromium-nickel steel) - it is necessary to use a press with relatively high pressure, i.e. above 2000 kN. Too low rubber pressure causes local sheet creasing. The intersection of stiffening grooves can be an area of significant weakening of the material.

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