Simulation of thin-sheet metal blanking and punching by elastic mediums

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Abstract. The paper describes the processes of thin-sheet workpiece blanking/punching using an elastic tool in an open and closed container. Finite element models are constructed, which describe the process of separation of the workpiece by an elastic workplace tool. A comparative analysis of the geometrical dimensions of the workpieces obtained as a result of theoretical and experimental studies was carried out.

Polyurethane materials have long been used as a workplace tool in various sheet metal forming operations. Recently, the use of polymers exactly as a tool is especially important. This is due to the growth of such industrial areas as construction, aircraft manufacturing, and mechanical engineering. In recent years, they have been the most interested in obtaining high-quality thin-sheet material with a different profile and a relatively low price.

A special place in the processing of sheet metal using an elastic medium occupy the processes of blanking and punching, which have found application primarily in the aviation industry. Parts from aluminum alloys are mainly manufactured using this method: ribs, frames and their parts, diaphragms, webs, bulkheads, half-tubes. Structurally, such parts are flat walls flanged at their edges, with flanged holes and stiffeners. Sheet metal forming processes using elastic media (polyurethane) have long been used in our country, mainly in small-lot manufacturing, since in this case the shearing operation process has several advantages compared with other types of stamping [1]. Cutting parts with an elastic tool, performed in universal equipment, is the simplest in execution, with cost savings achieved by reduction of [2–9]:

- Tooling design costs (10-20 times);
- Labour content of tooling manufacturing (20-30 times);
- Specific consumption of metal per tooling (hundreds of times);
- Tooling warehousing and storing costs;
- Straightening and deburring costs.

It is also necessary to take into account the fact that one former can sometimes replace two or more punch tools of various purposes, since when cutting with an elastic tool it is easy to combine the operations of cutting, forming and bending.
The simplicity and low cost of die tooling, the minimum duration of pre-production and the possibility of manufacturing parts on conventional press equipment makes it possible to consider methods of stamping by polyurethane as the most cost-effective ones when manufacturing parts from 2 pieces to 25 thousand pieces. Especially high in demand is the method of parts stamping by polyurethane for pilot and small-lot manufacturing, characterized by frequent product changeovers, as well as tight deadlines for pre-production [10–12].

Thus, the introduction of polyurethane in the industry has allowed to create a qualitatively new type of stamping that can compete with such well-known methods as element-by-element stamping, stamping in plate-type dies, stamping with liquid and gaseous media, magneto- and electrohydropulse stamping.

However, these processes by the nature of the stress-strain state are significantly different from the well-studied processes of traditional blanking and punching in rigid dies.

Most of the parts are produced by blanking or punching in a closed container, but the processes of metal separation and the accuracy of the parts obtained are theoretically not studied at all, which prevents widespread implementation of these promising technologies.

An obvious requirement for the process being developed is to obtain parts of a given quality, therefore the lack of theoretical studies of the processes of blanking and punching with elastic medium leads to significant difficulties in the implementation of these progressive processes in industry [13].

We were faced with the task of developing mathematical models to determine the force parameters of the blanking process in an open and closed container, also allowing to predict the geometry of the workpieces produced, and then compare the theoretical data with the data obtained during the experiment.

The geometrical scheme of blanking processes in an open container is shown in figure 1:

![Figure 1. Diagram of the blanking process in an open container: 1 – movable punch, 2 – elastic tool, 3 – workpiece, 4 – die.](image)

We have modeled the process of blanking copper (M1), aluminum (AMC) and stainless steel (12X18H10T) materials for different thicknesses of sheet metal workpieces using an elastic medium as a tool (the simulation results are presented in figures 2 – 3). The thin-sheet metal separation process was modeled using the ANSYS / LS-DYNA software package. When creating the finite element model, it was assumed that the die 4 and the punch 1 are absolutely rigid bodies. It was also assumed that the process is running at a constant temperature with a low strain rate. The elastic tool 2, made of polyurethane SKU-7L, acts on the workpiece 3 with a thickness of 0.5 to 1 mm, which is placed on a fixed rigid die 4. A view of the finite element model of copper workpiece blanking by an elastic tool (in brackets process time in seconds is indicated) is shown in figure 2a. The separation process can be divided into four stages. At the first stage (figure 2b), an elastic tool interacts with the workpiece, the
free edges of which are bent, and the process of penetration of a rigid punch into the metal begins. Thus, at the first stage of the process, the plastic strain zone forms in the area of rigid punch penetration into the workpiece. At the second stage of the process (figure 3c), due to the accumulation of plastic strain in the deformation zone, the separation of the workpiece begins under the action of shear deformations.

![Plastic strain zone formation and microcrack initiation](image)

**Figure 2.** Stages of the workpiece deformation before the crack initiation.

The stage ends with initiation of a microcrack. In the third stage of the process, shown in figure 3 (a, b), the initiated crack increases by about half of the workpiece thickness. In the fourth stage of the process, the final separation of the workpiece and waste occurs in form of a brittle cleavage under the action of tensile stresses with the formation of a characteristic shrinkage depression and cleavage at position of fracture.

To verify the theoretical calculations, a series of experiments were carried out on blanking parts with elastic medium in a closed and open container on an INSTRON SATEC press. The blanking processes in a closed container are shown in figure 4a, and in an open container – in figure 4b. Figure 5 shows some blanked parts.

Figure 6 shows comparative graphs of the change in the deformation force acting on the aluminum workpiece (AD1) during a blanking operation, obtained as a result of calculations and experiments performed. From the presented graphs it can be seen that the behavior of the theoretical and experimental curves coincides quite well. The graph at the time of the waste separation (0.042 sec) shows a characteristic jump of a force.

Figure 7 shows the measurement scheme of the separation zones of the part produced by blanking in an open container. Figure 8 shows the view of separation zones of the parts produced by blanking and punching.
Figure 3. Stages of the workpiece separation before fracture.

Figure 4. Test installation.
Figure 5. Details produced during the experiment.

Figure 6. Change of deformation forces during the blanking operation.

Figure 7. Measurement scheme of the part separation zones.
Conclusions
As a result of our work, we have developed dynamic mathematical models for blanking and punching of thin-sheet metal with an elastic tool that is enclosed and not enclosed in a closed container. The stress-strain state of the system “an elastic working tool – a deformed metal” has been determined. Due to the fact that the workpiece produced by this method has a low quality (rather large geometric distortions of the separated portion and part in the cut zone are observed), this method of cutting thin sheet metal can be recommended for manufacturing non-critical parts that do not require high accuracy.

Comparison of the results of the derived theoretical solutions with experimental data obtained by us in regards to the shape distortion of blanked workpieces, the types and geometry of separation zones, as well as the force parameters of the process make it possible to state that the calculations on the developed models show fairly high accuracy for both soft aluminum alloys and corrosion-resistant steels.

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