3D Printed Plastic Tool for Al Thin-Sheet Forming

L B Aksenov1,* and I Y Kononov1

1Peter the Great Saint-Petersburg Polytechnic University, 194064, Polytechnicheskaya 29, Russia

*Corresponding author: l_axenov@mail.spbstu.ru

Abstract. Shown prospects of 3D printed plastic tooling in the processing of metal forming. The study of the process of thin sheet forming of aluminum 3003 ANSI established that in this process of destruction and plastic deformation of the plastic tool does not occur. Lubrication of plastic matrices and punches were not required, as they have anti-friction properties. Computer simulation of this process in the software system "Simufact.forming" accurately reflects the force parameters, stress-state of plastic tool and the actual course of the process of forming the blank, including the spring-back of the part after forming. Technology of sheet forming with plastic tool can be recommended for single and small batch production.

1. Introduction

3D printing is common technology and it is applied for rapid manufacturing of finished parts or prototypes of the materials supported by 3D-printers. The positive experience was obtained in various industries: medicine, manufacture of household appliances, furniture, clothing, in the construction of buildings and structures and [1]. Technologies of 3D printing have a high-performance, high-speed and cost-effective for small-lot and piece production. The main purpose of the use of products manufactured using 3D printing is reducing the cost of manufactured products, accelerations of prototyping and product development, customizing products for a specific customer.

Achievements of 3D printing in metal forming are not so wide, but one of the first positive applications in the dies manufacturing was done more than 20 years ago [2]. The role of 3D printers is also significant and promising part of the design and implementation of production with technologies of metal forming [3]. As for to sheet forming, tool manufactured by techniques of 3D printing in some cases is able replace metal tools. There is evidence that the use of 3D printing is capable of 80% reduction in time spent on development and manufacture of tooling and to reduce the cost of tooling by 70% [4-5].

Among the many types of 3D printers, printers for the manufacture of plastic products are much cheaper compared with printers which are designed to operate with metal or other materials [6]. Therefore, the possibility of using the plastic tool is the most economically advantageous in cases when it is possible and, first of all, it is the field of small-batch and unit production [7].

Great attention to this process pays the automotive industry, seeing the future in the production of spare parts and individual tuning of motor cars [8-9]. Interesting can be called the use of plastic tool for sheet hydroforming of parts of the aviation industry [10]. However, the area of possible application of the plastic tool in metal forming is just beginning to be defined.

The use of 3D printing to improve design processes die forging can be successfully carried out already at the present stage of development of the technology of 3D printing. So, it is possible to print models of dies and to use them for physical modeling of processes with a certain ratio of geometric
similarity for the purpose of determining the deformation of metal during stamping, and also to check the adequacy of the methods of computer modeling [11]. In this case the cost and time of conducting the physical simulation is significantly reduced compared to the use of metal tool which is made in traditional ways.

In the present paper shown the possibility of application of 3D printed plastic tooling for cold forming of thin sheet aluminum.

2. Used equipment
For the manufacture of plastic dies on the basis of information from open sources [12,13], was designed and assembled special 3D-printer (Fig.1), which belongs to the group of Fused Deposition Modeling (FDM) 3D-printers.

![3D-printer to manufacture plastic dies.](image)

The following print settings of the printer were used:
- Type of plastic: polyethyleneterephthalate.
- Print resolution on the X and Y axes, depending on the diameter of the extruder nozzle - 0.4 mm.
- Print resolution on the vertical Z-axis (layer thickness) - 0.2 mm.
- Print speed - 30 mm/s.
- The temperature of the extruder - 245 °C.
- Temperature of heating table - 110 °C.

3. Thin sheet forming with plastic tooling
A study of forming by plastic tooling of part for micro heat exchanger from thin sheet aluminum ANSI-3003 (Fig. 2) was done (Fig. 2). The parameters of used blanks as follows: aluminum sheet material of ANSI 3003; thickness: 0.1 mm; length and width are 30 mm. In the forming process were used three sets of dies. The working surface of the dies had periodic profile with the tooth height h=2, 3 and 4 mm with the number of bends 12, 9 and 5, respectively.
Figure 2. Sketch of plastic dies with the relief height $h=2$, 3, 4 mm (a) and the process of their manufacture on a 3D printer with a view of the internal structure (b).

In Fig. 3a presented the main stages of process of forming of sheet blanks in the plastic dies, and in Fig. 3b examples of elements of micro heat exchangers manufactured using this technology.

The maximum of forming force amounted to 1350 N for the profile with the tooth height of 2 mm, 700 N for the profile with the tooth height of 3 mm and 500 N for the profile with the tooth height 4 mm. At equal size of the workpiece the forming force increases with decrease of the height of the formed profile. This reflects the dependence of the force from the number of formed teeth, i.e. the number of bends in the workpiece, which increases with number of teeth.

The final height of formed tooth profile is in the range of 45-65% of the height of the tooth on the die. It is connected with the elastic deformation (spring-back) of the sheet workpiece after forming. There is also uneven distribution of the height of the tooth along width of the workpiece.

The smallest tooth height is observed in the central parts and the height gradually increases from the center to the edges of the part. In addition to the elastic spring-back there is a phenomenon associated with the presence of friction and resistance to kinking that occurs due to "tightening" of the material to the center of the die during the forming.
Figure 3. The process of sheet forming in plastic dies with a teeth height h= 4, 3, 2 mm (a) and elements of micro heat exchangers made by forming in plastic dies (b).

In addition, as a result of the described factors, the formed parts received have some deviation from the plane. For these details, it doesn't affect their performance characteristics, as do not change parameters of heat exchange, and the deviation from the plane is compensated when connecting heat exchanger with other parts of the unit.

4. Computer simulation of sheet forming with plastic tooling

Computer simulation of sheet forming process was performed in the software package „Simufact.forming“ [14]. For the calculation were set to: characteristics of the workpiece material; the geometry of the dies and the workpiece; the type of process -cold sheet forming; the movement of the punch, providing at the final moment of forming the gap between the dies equal to the thickness of formed material. In the calculations it was used the elastic-plastic model material of the blank DB.ALMn from the database „Simufact.material“ taking into account the deformation hardening of metal corresponding to the ANSI 3003 aluminum [15].

In the simulation was used a mesh with rectangular finite elements (Fig. 4a). Nine elements were located at the thickness of the workpiece. Totally in the model were used for about 30 thousand elements. One calculation takes approximately 60-90 minutes.

The distribution of values of effective stresses during forming of the workpiece (Fig. 4a) shows that the highest values of stress are observed in the outer layers of the bent workpiece, where summation takes place the stresses of the same sign from bending and stretching of the workpiece.

During the forming the maximum force of deformation reached 1350 N. On the area of the workpiece 900 mm² average pressure on the tool was 15MPa. At this pressure, fracture, plastic deformation or scratches on the working surface of the plastic tool was not observed.

Lubrication of the dies was not held because they have anti-friction properties. Similar results are obtained by computer simulation of stress state of plastic dies (Fig. 4b). As a model for material of dies was chosen an elastic body with a modulus of elasticity equal to 2400 MPa, obtained according to test method ASTM D790 [16]. The simulation showed that the maximum value of the effective stress in the dies is corresponding to the end of the forming, about 35 MPA, which is less than the value of yield stress, which is 52 MPA. Thus, simulations and experiments show that plastic dies in the studied process are in the elastic state.

After forming a few dozens of parts noticeable wear of the plastic dies was not detected. Steps of simulation of forming the workpiece is shown in Fig. 5. The model of formed material of the workpiece
has elastic properties, which allows reproducing the change of geometry (elastic spring-back) of parts after forming.

The simulated dimensions of the parts differ from those obtained when forming not more than 0.2 mm in height molded profile, which is of the order ±15%. The calculation of the required forming force coincides with the experimental data with an accuracy of ±10%. Thus, computer simulation of the forming process by plastic dies accurately reproduces the geometrical and force parameters of the real process.

Studied process of sheet metal forming has main advantages of 3D printing: economic efficiency, as the forming by plastic dies are much cheaper than forming by metal dies or with the use of the mix of polyurethane and metal dies because of the low cost of the tool and a significant acceleration of production. The conducted research allow to recommend the technology of thin sheet forming with the use of plastic tools, for single and small batch production.

![Figure 5. Stages of simulation of the forming process (a) and the shape of the product (b) obtained by simulation in the software package „Simufact.forming“ (1) and experimentally (2).](image)

The future development of plastic tool for metal forming technologies is seen in the improvement of technology of manufacturing plastic tool (their structure, method of applying a layers, etc.) and their application to a greater number of technological processes and to manufacture not only the forming elements but also the die blocks in assembly.

5. Conclusion

- On the example of forming process of thin sheet forming of aluminum it is shown that plastic tool, manufactured using 3D printing, can be successfully used for metal forming if the effective stresses in the tool do not exceed the elastic limit for plastic.
- When forming plastic tool is not destroyed, plastically not deformed and possess sufficient wear resistance. Lubrication of plastic dies is not required, as they have anti-friction properties. Technology of sheet forming with the use of a plastic tool can be recommended for single and small batch production.
- Computer simulation in the software package "Simufact.forming" accurately reflects the required force for thin sheet forming with plastic tool, distribution of stresses in the tool and also actually course of forming of the blank, including the shape changing of the part after the forming as a result of the elastic spring-back.

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