Study of side stamping under one-sided magnetic pulse loading on form blocks of various materials

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Abstract. In this paper, the influence of the tooling material on the accuracy of forming the resulting aluminum alloy part under one-sided magnetic pulse loading was estimated. As the materials of the form blocks were used: dry pine, steel 45 and PLA-plastic. Numerical simulation was carried out using the ANSYS software package in the Explicit Dynamics module. Studies have shown the dependence of the nature deformation of the workpiece and the final geometry of the resulting part from the mechanical properties of the form block materials.

1. Introduction

Magnetic pulse stamping (MPS) of parts has been used since the end of the 50's of the last century, however, despite the fairly extensive experience in researching this process [1-8], the actual practical application of the technology in aircraft production has a number of practical difficulties [4, 9–13]. One of these problems is the choice of the optimal material of technological equipment for precise shaping of aluminum alloy profiles by a pulsed magnetic field (PMF). Obtaining high-quality geometry profiles of aircraft by magnetic pulse processing (MPP) is complicated by the asymmetry of the pulse loading, which imposes increased requirements for the choice of material of forming surfaces in comparison with conventional stamping conditions. The purpose of this work was to assess the impact of tooling on the accuracy of forming of the resulting aluminum alloy part in magnetic pulse stamping (MPS) processes with one-sided loading.

2. Methodology of theoretical research

To determine the effect of the tooling material on the accuracy of forming the resulting aluminum alloy part under one-sided magnetic pulse loading, a simulation of magnetic pulse stamping of the straight side of various form block materials was performed (shown in Figure 1) using the ANSYS software package in the Explicit Dynamics module. The calculation area consisted of three parts: the workpiece, the form block and the inductor. The thickness of the workpiece was 2 mm, and the height of the stamped side was 7 mm. The sizes of the form blocks were chosen deliberately large sizes of samples with a radius of rounding along the bending line equal to 3.2 mm. The lower surface of the form block and the upper surface of the inductor were restricted by absolutely rigid barriers. A restriction on waste was imposed on the left edge of the workpiece, which in practice corresponds to a more reliable fixation of the workpiece on the hairpin holes. When the surfaces of the workpiece and the form block, the workpiece and inductor come into contact, contact with friction is assumed.
Modeling of the inductor was carried out exclusively to impose restrictions on the significant waste of the workpiece from the form block. Each calculated area was divided into quadrangular cells with automatic meshing. The total number of finite elements of the model was 5494.

![Figure 1. Scheme of loading by a pulsed magnetic field (PMF).](image)

The mechanical properties of the workpiece material corresponded to the AMuM aluminum alloy [1]. As a model of the material used: bilinear-hardenable model. To account for the high-speed deformation of the material, instead of the static yield strength, a dynamic yield strength \( Y_0 \) was used.

The dynamic yield strength of the AMsM alloy was estimated at the strain rates corresponding to magnetic pulse loading, was carried out using the method described in [14]. The estimated value was \( Y_0 = 120 \text{ MPa} \).

The mechanical properties of the workpiece material corresponded to: dry pine, steel 45 and PLA-plastic (PLA brand). All material specifications were taken from the ANSYS material library.

The calculation of the parameters of the discharge circuit of the magnetic pulse generator-inductor-workpiece system was carried out according to the methods described in [14, 15]. The estimated value of the frequency of the discharge circuit \( f \) was 20 kHz.

The pressure of the PMF \( P_{PMF} \) on the fixed workpiece was set by a decaying quadratic sinusoid [16] with only the first half-period of loading:

\[
P_{PMF} = P_0 \sin^2(2\pi ft)
\]

where \( P_0 \) represents pressure amplitude, \( f \) represents discharge current oscillation frequency.

The pressure attenuation of the PMF when moving away from the inductor was not taken into account, since the calculations used a sufficiently large value of the frequency of the discharge circuit in 20 kHz. The amplitude of the magnetic pressure \( P_0 \) varied in the calculations from 10 to 150 MPa. The purpose of the numerical simulation was to determine the optimal pressure values of the PMF at which the most accurate part is manufactured with non-fit to the form block acceptable in aircraft manufacturing (less than 0.5 mm).

### 3. Numerical simulation results

Figure 2 shows the results of modeling the bending of the straight side by pressure of the PMF on a dry pine form block. With an increase in the PMF pressure, a predictable increase in the bending angle of the workpiece is observed (Figure 2 a, b). At a certain bending angle, due to the elastic properties of the material of the form block, the workpiece begins to spring from its radius part (Figure 2 c). A further increase in the pressure of the PMF does not allow increasing the fit of the side to the form block and begins first to lead to side lengthening and thinning of the material on the radius part of the workpiece (Figure 2 d, e), and then also increases the overall spring of the side and non-fit to the form.
block (Figure 2 f). At a pressure of about 140 MPa, the side is torn off on the radial part of the form block. Thus, the numerical simulation of the straight side bending by the pressure of the PMF on the dry pine form block shows the fundamental impossibility of obtaining parts with specified accuracy characteristics.

Figure 2. Kinematics of forming a workpiece on a dry pine form block: a – 30 MPa; b – 40 MPa; c – 50 MPa; d – 60 MPa; e – 70 MPa; f – 140 MPa.

Figure 3 shows the results of modeling the bending of the straight side by PMF pressure on the form block of steel 45. With an increase in the PMF pressure, there is also a predictable increase in the bending angle of the workpiece (Figure 3 a, b, c) and at an optimal pressure value of about 60 MPa, it is possible to obtain parts with minimal non-fit to the form block (Figure 3 e). A further increase in PMF pressure leads to side lengthening and thinning of the material on the radius part of the workpiece (Figure 3 d). At a pressure of about 125 MPa, the side is torn off on the radial part of the form block (Figure 3 f). Thus, the numerical simulation of bending the straight side of the PMF pressure on the form block of steel 45 shows the possibility of obtaining parts with maximum precision characteristics.
Figure 3. Kinematics of forming a workpiece on a steel 45 form block: a – 30 MPa; b – 40 MPa; c – 50 MPa; d – 60 MPa; e – 80 MPa; f – 125 MPa.

Figure 4 shows the results of a simulation of a straight side bending by PMF pressure on a PLA-plastic form block. The kinematics of the side forming on the PLA-plastic form block is similar to the kinematics on the dry pine form block (Figure 4 a, b, c), except for the possibility of obtaining a part with non-fit to the form block in the specified tolerance (Figure 4 c). Obviously, this is due to the lower stiffness of the plastic compared to dry pine. The workpiece crushes the radius part of the form block and due to this, the part is formed. In addition, in the process of deformation of the workpiece at the end of the impulse of applying PMF load, a significant “squatting” of the form block is observed (Figure 4 d). Obviously, in the actual manufacture of a part on such a form block, a gradual destruction of the tool will occur over time. With a further increase in pressure, as in the case of dry pine, the springing of the part increases and at a pressure of about 150 MPa, the side is torn off on the radial part of the form block (Figure 4 e). Thus, the numerical simulation of bending a straight side with the pressure of PMF on a PLA-plastic form block shows the possibility of obtaining parts with the required accuracy characteristics, but in practice this may be difficult due to the need for more accurate dosing of pulse energy and the possibility of destruction of the form block.

In general, in the transition from a less rigid material (PLA-plastic) to a more rigid material (steel 45), a decrease in the time of the forming process is noted due to the smaller contribution of the elastic characteristics of the tooling material to the value of the workpiece spring. With low stiffness of the material of the form block in the process of forming the workpiece, some fluctuations in the geometry
of the tool are observed. These fluctuations in the geometry of the form block affect the workpiece in contact with it and cause an increase in the time of the forming process.

![Kinematics of forming a workpiece on a PLA-plastic form block](image)

**Figure 4.** Kinematics of forming a workpiece on a PLA-plastic form block: a – 30 MPa; b – 50 MPa; c – 60 MPa; d – 50 MPa at time 2.2 μs; e – 145 MPa.

4. **Conclusion**

Thus, numerical studies using the finite element method of one-sided loading by a pulsed magnetic field of form blocks of various materials have shown:

- The most optimal material for use in form blocks with one-sided loading by a pulsed magnetic field is steel.
- With increasing rigidity of the materials of the form blocks in the process of flat magnetic pulse stamping, the value of springing of finished products decreases.
- When applying certain assumptions, numerical simulation of magnetic pulse processing can be performed in the ANSYS software package in the Explicit Dynamics module.
- Experimental studies are required to evaluate the accuracy and verify the validity of the numerical study performed using the Explicit Dynamics module of ANSYS program.

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