Development of Methods and Equipment for Sheet Stamping

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Abstract. New methods of sheet stamping were developed: the gas forming with double-sided heating of a blank part and the gas molding with backpressure. In case of the first method the blank part is heated to the set temperature by means of a double-sided impact of combustion products of gas mixtures, after which, under the influence of gas pressure a stamping process is performed. In case of gas molding with backpressure, the blank part is heated to the set temperature by one-sided impact of the combustion products, while backpressure is created on the opposite side of the blank part by compressed air. In both methods the deformation takes place in the temperature range of warm or hot treatment due to the heating of a blank part. This allows one to form parts of complicated shape within one technological operation, which significantly reduces the cost of production. To implement these methods, original devices were designed and produced, which are new types of forging and stamping equipment. Using these devices, an experimental research on the stamping process was carried out and high-quality parts were obtained, which makes it possible to recommend the developed methods of stamping in the industrial production. Their application in small-scale production will allow one to reduce the cost price of stamped parts 2 or 3 times.

1. Introduction

Sheet stamping ensures a significant metal saving. Therefore, sheet stamping is widely used in many industries. However, traditional methods of sheet stamping are effective only in large-scale production; in many industries the share of small-scale productions is significant [1], in particular in chemical, power engineering and aerospace industries.

In small-scale production, sheet stamping methods based on the application of pulsed energy sources are more effective, in particular, hydrosupply stamping [2], i.e. stamping by impact through an intermediate liquid or elastic medium [3], stamping with combustion products of gas mixtures [4], gas-denotation stamping [5], and electrohydraulic stamping [6]. In small-scale production, these methods lead to a significant cost in the production of stamped products due to the reduction in cost of die equipment and the machines used.

In the methods described above, the stamping process takes place in the cold state of the blank part which significantly limits the technological capabilities of these stamping methods. Many alloys of aluminum, titanium, molybdenum, tungsten have a low plasticity; therefore, when stamping parts of complicated shape, it is necessary to heat the blank part to the temperature range of warm or hot treatment.

There is another method known as gas-thermal molding [7]. This method suggests application of inert gas to the blank part for a long time. The part is heated and distorted. However, due to the high energy consumption this method is very expensive.

Taking into account the information mentioned above, it can be concluded that the development of new sheet-stamping technologies that ensure efficient heating of stamped blank part and its subsequent deformation is an urgent task, especially with regard to small-scale production.

2. Materials and methods

The purpose of this work is to develop new methods of sheet stamping with blank part heating in relation to small-scale production. To achieve this goal, the authors have developed a method of gas stamping with double-sided heating of the blank part and a method of gas molding with backpressure.

The diagram of the device for gas stamping with double-sided heating of the blank part is shown in Fig. 1. The device comprises matrix 1 and combustion chamber 2 provided with inlet valves 4, 8, exhaust valves 6, 9 and spark plugs 5, 7. Stamped blank part 11 is clamped between combustion chamber 2 and annular piston 13. Combustion chamber 2 and die cavity 1 through inlet valves 4 and 8 are filled with a fuel mixture, for example, natural fuel gas and compressed air.

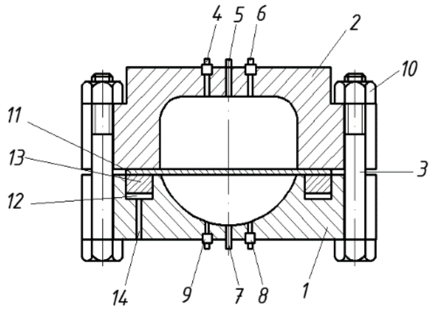

Figure 1. Diagram of gas stamping device: 1 - matrix; 2 - combustion chamber; 3 - bolt; 4.8 - inlet valves; 5.7 - spark plugs; 6.9 - exhaust valves; 10 - nut; 11 – blank part; 12 - cavity; 13 - annular piston; 14 - channel

Fuel mixture is ignited with candles 5 and 7. As a result of the combustion of the fuel mixture, both pressure and temperature increase 7 to 8 times. Under the influence of the combustion products, blank part 11 is intensively heated for a certain time. After the temperature of blank part 11 reaches the set value, exhaust valve 9 opens and the gas is discharged from matrix 1. In this case, under the influence of the gas pressure in combustion chamber 2, blank part 11 deforms and fills the cavity of matrix 1.

What should be the pressure of the fuel mixture to ensure the filling of the entire cavity of the matrix? The carried out research has shown that the necessary pressure value of a fuel mix can be defined with the following dependence [8]:

$$\boldsymbol{P_c} = \frac{\mathbf{1}}{\boldsymbol{\lambda_v}}\frac{\mathbf{1}}{\mathbf{1}-\boldsymbol{\tau}_{\text{н}}}\frac{\mathbf{2}\boldsymbol{\delta}}{\boldsymbol{R_{min}}}\boldsymbol{\sigma_s}\left(\mathbf{1}+\frac{\boldsymbol{V}_{\text{м}}}{\boldsymbol{V_k}}\right)^{\boldsymbol{k}} \quad (1)$$

where, $V_{М}$, $V_{К}$ are the volume of the matrix and combustion chamber; k is the adiabatic exponent; σ_s is the yield point of the blank part of material; λ_v is the degree of pressure increase when the fuel mixture burns at a constant volume; δ is the thickness of the blank part; $\tau_н$ is the blank part heating time; $\boldsymbol{R_{min}}$ is the minimum radius of curvature of the blank part surface. When calculating yield stress σ_s basing on dependence (1), the blank part heating temperature should be taken into account.

Theoretical and experimental studies of blank part heating process were carried out to determine the heating temperature of the blank part to be stamped. It was found that the optimum heating time of the blank part is 0.3 ... 0.4 s. The following dependence for calculating the temperature of blank part was obtained [9]:

$$\Delta t_з = \frac{2\alpha(t_Г - t_з)_{cp}}{\delta\rho_з c_з}\tau \quad (2)$$

where, $\Delta t_з$ is the temperature increment of the blank part; $(t_г\text{-}t_з)_{ср}$ is the average value of the temperature difference between gas and the blank part; $\rho_з$ is the density of the blank part material; α is the heat transfer coefficient; $\boldsymbol{c_з}$ is the specific heat of the blank part material.

Heat transfer coefficient α, which is part of dependence (2), mostly depends on the pressure of the fuel mixtures. As the pressure increases, value α increases and the temperature of the blank part increases accordingly. Therefore, the pressure of the fuel mixture is a powerful factor ensuring controllability of the blank part heating process. In particular, the pressure of a fuel mixture of 1 ... 1.1 MPa is sufficient to heat a steel blank piece with the thickness of 1 mm up to 850 ... 900 ° C, i.e. up to the lower limit of a hot working temperature range.

Several experiments were carried out to test the developed method and evaluate its technological capabilities. To do so, an experimental device designed on the basis of the diagram shown in Fig. 1 was used. In the course of experiments, a cylindrical matrix was used, as well as a matrix in the form of a lattice. During the experiments the pressure of the fuel mixture, as well as the pressure of the blank part pressing and the heating time of the blank part, varied. Using a cylindrical matrix, at a relatively low pressure of the fuel mixture, spherical bottoms of different depths were stamped using steel 3 with the thickness of 1 mm. In particular, when the pressure of the fuel mixture was 0.4 MPa, the spherical bottoms with the depth of 138 ... 140 mm were obtained; one of them is shown in Fig. 2. The heating time of the blank part amounted to 0.4 s.

Using a lattice matrix, honeycomb panels with the square cells of 90x90 mm were stamped. Similar parts are used in the aircraft building. They are produced by milling or isothermal molding [7]. Honeycomb panels made from 2 mm thick aluminum sheet were stamped in the course of experiment. The fuel mixture pressure of 0.4 ... 0.5 MPa ensured obtaining good quality parts (Fig. 3). The heating time of the blank part was 0.4 s.

Figure 2. Spherical bottom

Figure 3. Honeycomb panels

In general, the results of the conducted experimental studies have shown that the method of gas stamping with double-sided heating of the blank part is applicable for stamping parts of both simple and complicated configuration with small curvature radii. The method provides for stamping parts of a complicated shape within one technological operation, which reduces the cost of production. Therefore, this method can be effectively used in small-scale and pilot production for stamping parts of a wide range.

However, this method is not efficient for stamping small parts with the shape of a cover or shell, which are widely used in many devices, in particular in heat exchangers and machines as well as devices of food and chemical industries [10]. This is due to the fact that the cavity of a matrix of such parts has a small height. In such matrix it is difficult to initiate the combustion process of the fuel mixture and to provide uniform pressure on the surface of the blank part. Taking this fact into account, a method of gas molding with backpressure was developed to stamp thin-walled parts having a small height.

This molding method is carried out using a device the diagram of which is shown in Fig. 4. A distinctive feature of this device is that cylinder 11 with piston 10 is fixed to body 2. Cavity 9 of cylinder 11 is communicated with combustion chamber 5 and cavity 12 is connected by pipeline 13 to cavity 18 of matrix 17.

The device operates in the following manner: In cavity 18 of matrix 17, a compressed air is supplied through valve 21 flowing through pipeline 13 into cavity 12 of cylinder 11. Simultaneously, the fuel mixture components are fed through valve 6 to combustion chamber 5: a combustible gas and a compressed air. The pressure of the fuel mixture in combustion chamber 5 is set equal to the air pressure in cavity 18 of matrix 17. The fuel mixture is ignited with candle 7. At the time of the combustion of fuel mixture, the pressure in combustion chamber 5 rises. This pressure is also transferred to cavity 9 of cylinder 11. In this case, under the influence of gas pressure, piston 10 moves displacing the air from cavity 12 into cavity 18. This causes an increase in pressure in combustion chamber 5 and in cavity 18, which limits the deformation of blank part 16 and prevents its contact with the surface of the matrix. After the combustion of the fuel mixture has finished, blank part 16 remains under the influence of the combustion products and is heated intensively for some time. When the temperature reaches a predetermined temperature range, valve 22 opens and the air is exhausted from cavities 18 and 20. In this case, under the influence of the pressure of the combustion products, preform 16 fills cavity 18 of matrix 17 - the molding process is carried out.

In order to implement this molding method, the pressure in cavity 18 of matrix 17 should vary according to the pressure change in combustion chamber 5, especially in the final stage of the combustion process of the fuel mixture. This is ensured by the appropriate selection of design parameters of the molding device [11].

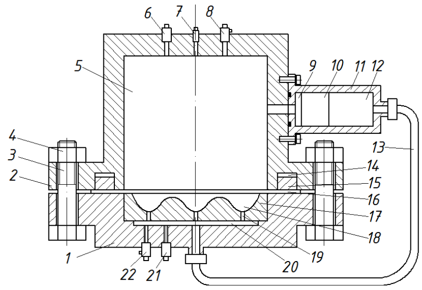

Figure 4. Diagram of the device for sheet gas molding: 1 - matrix holder; 2 - housing; 3 - bolt; 4 - nut, 5 - combustion chamber; 6.21 - intake valves; 7 - spark plug; 8.22 - exhaust valves; 9,12, 14,20 - cavities; 10 - piston; 11 - cylinder; 13 - pipeline; 15 - annular piston, 16 - blank; 17 - matrix; 18 - matrix cavity; 19 - channel

When molding parts with the complicated shape, the greatest gas pressure is required to mold the sections with minimal curvature radii. Therefore, the required pressure of the fuel mixture is determined by the following dependence [11]:

$$P_{\text{с}} = \frac{2a\delta\sigma_s}{\lambda_V R_{min}} \left(1 - 0,1\frac{\tau_{\text{н}}}{\tau_z}\right)^{-1}, \qquad (3)$$

where, $\tau_{\text{н}}$ is the heating time of the blank part at the end of the combustion process, s; τ_z is the combustion time of the fuel mixture, s; a is the coefficient, depending on the volume of the molded part. In case the calculations are done on the basis of the dependence (3), the value of the yield point σ_s should be taken with respect to the heating of the blank part. It is also necessary to know the heating time of the blank part $\tau_{\text{н}}$. In this connection, both theoretical and experimental studies related to blank part heating have been carried out [12]. It was found out that the optimal heating time for the blank part is 0.4 ... 0.5. To determine the temperature of the blank par, the following dependence was obtained:

$$t_{\text{з}} = \frac{1}{b+1}\left[t_z\left(1 - e^{\frac{\alpha(b+1)\tau}{\rho_{\text{з}} c_{\text{з}} \delta}}\right) + t_{\text{з}_0}\left(b + e^{-\frac{\alpha(b+1)}{\rho_{\text{з}} c_{\text{з}} \delta}\tau}\right)\right]. \qquad (4)$$

$$b = \frac{F_{\text{с}} + F_{\text{з}}}{F_{\text{з}}}\,\frac{\rho_{\text{з}}\delta F_{\text{з}} c_{\text{з}}}{\rho_{\text{г}} c_{\text{г}} V_{\text{к}}}, \qquad (5)$$

where, t_z is the initial temperature of gas equal to the end temperature of the combustion process, °C; $t_{\text{з}_0}$ is the initial temperature of the blank part, °C; $F_{\text{з}}, F_{\text{с}}$ are the areas of heat-sensing surface of the blank part and the combustion chamber; $t_{\text{г}}$ is the gas temperature; $t_{\text{з}}$ is the temperature of the blank part; $\rho_{\text{г}}$ is the density of gas in the combustion chamber; $c_{\text{г}}$ is the specific heat of gas at constant volume.

Experimental studies were carried out to assess technological capabilities of this molding method. The experiments were carried out on the equipment designed according to the constructive diagram, shown in Fig. 5. The photo of the equipment is shown in Fig. 5. During the experiments, the sheet blank parts of aluminum of grade A5M with the thickness of 0.5 mm, 1 mm, 2 mm and blank parts of steel 3 with the thickness of 0.5 mm and 1 mm were molded. Besides, the pressure of the fuel mixture varied between 0.3 ... 0.7 MPa and the pressure pressing on the flange part of blank part varied in the range of 1.5 ... 7 MPa. At the same time, the molding technology was developed for the following parts: spherical bottom, spherical bottom with a flat bottom, spherical bottom with central cavity, cylindrical part with flange, parts with the surface of double curvature, parts with shallow relief and heat exchanger panels with spiral channel. As a result of the work, the parts of good quality were obtained. Some of them are shown in Fig. 6 and 7. The quality of the obtained parts shows that this molding method has significant technological capabilities and can be effectively applied for the industrial purposes, especially in small-scale production.

Figure 5. Experimental installation for gas molding with backpressure

Figure 6. Spherical bottom with central cavity

Figure 7. Heat exchanger panel with spiral channel

3. Conclusion

1. To carry out sheet stamping when the blank part is heated, new methods of gas stamping were developed, which ensure the stamping of parts with complicated shape within one technological operation. Experimental studies have confirmed their high efficiency, which makes it possible to recommend their application for the industrial purposes.

2. To heat the sheet blank part, one side of the blank part can be affected by high-temperature gas directly in the cavity of the die tooling. The most intensive temperature rise of the blank part is provided by two-sided heating. Therefore, if the combustion process is possible taking into account the volume and the shape of the matrix, then two-side heating is preferable.

3. To practically implement the developed methods of stamping, the original devices of new types of forging and stamping equipment have been designed and tested. The use of these devices in small-scale and pilot production can lead to a 2 or 3 times reduction in the production cost of stamped products.

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