Investigation of the combined process of isothermal crimping with a set of thickenings at the ends of pipe blanks

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Abstract. The article discusses the production of cylindrical hollow workpieces with different cross-sections along the height. The difference in cross-sections is ensured by crimping. During the crimping, the ends of the blanks are thickening. The operation under consideration is carried out in a hot state with local heating of the workpiece elements with a slow movement of the tool. It occurs due to the material grade of the workpiece, which is very demanding in terms of the deformation conditions. Simulation of the studied combined process has been carried out, during which the influence of the parameters of the main operations (deformation rate, heating parameters, friction) on the possibility of obtaining products with specified geometric characteristics has been established.

1. Introduction
Power plant piping systems include different types of elements that connect pipelines of various cross-sections. These elements interconnect piping systems of various diameters [1-4]. They are usually joined by welding, for which it is desirable to have some thickenings at the ends of the pipes. The products must be made of high strength and lightweight materials [5-8]. Therefore, obtaining and processing such parts is labor intensive. This article discusses the production of hollow cylindrical workpieces with varying cross-sections along the height by the crimping operation [9-12]. In addition, simultaneous crimping and thickening at the end of the workpiece is considered. In view of the fact that the material of the workpiece is titanium alloy Ti–6Al–4V, it is necessary to observe a certain temperature-rate interval of stamping, as well as local heating of various elements of the workpiece. Providing such difficult deformation conditions requires a scientific basis. In view of this, the article presents the results of simulation of the considered combined process, during which the influence of the main parameters of the operation on the possibility of obtaining products with given geometric characteristics is established.

2. Materials and methods
The study was carried out on the basis of computer simulation using DEFORM. It was assumed that a pipe blank made of Ti–6Al–4V titanium alloy was deformed. The temperature varied along the length of the workpiece within the range of 20–930°C. The workpiece had a diameter $D_0 = 80$ mm and wall thickness $t = 5$ mm. Figure 1 shows a diagram of the operation under consideration.

This process is characterized by simultaneous processes of crimping and thickening of the blank end. In view of the fact that the blank is made of high-strength alloys, the thickening which occurs simultaneously with crimping is very difficult to obtain under normal conditions of deformation.
3. Results and Discussion

Figure 2 shows diagrams illustrating the formation of the geometry of the workpiece under different conditions of forming for the crimping coefficient $k = 0.7$ and the taper angle of the die $\alpha = 15^\circ$. 

Figure 1. Scheme of the operation under consideration at the initial stage (a) and the final stage of deformation (b): 1 – die; 2 – mandrel; 3 – bushing; 4 – punch; 5 – blank

Figure 2. Products during crimping with thickening: 1 – $T = 20^\circ C$, $V = 600$ mm/min; 2 – $T = 930^\circ C$, $V = 2$ mm/min; 3 – $T = 930^\circ C$, $V = 600$ mm/min
Cold deformation of pipe blanks from this alloy also leads to a loss of stability in the form of the formation of transverse folds between the die and the mandrel. During the hot stamping with heating of the entire volume of the blank at deformation rates corresponding to a standard hydraulic press, folds are also formed. At low speeds of the tool, stability loss does not occur. However, it has been established that hot deformation at a constant temperature of the entire volume of the blank does not provide the required volume of thickening at the ends. Thus, it is necessary to select technological modes of forming, ensuring the absence of geometry defects and rational power modes of forming.

In particular, heating the entire volume of the blank does not ensure its stability during the stamping process. In addition, the end elements of the pipe blank are not formed in the required volume. It is proposed to ensure the forming of the blank with local heating of its elements. Figure 3 shows a diagram of a blank divided into elements with different heating temperatures. Local heating of the blank zones is provided by either heating or cooling of die elements. The blank zones with the temperature $T = 930^\circ C$ are marked in red, and with the temperature $T = 50^\circ C$ - in blue.

![Figure 3. The blank](image)

A number of computer experiments on deformation of pipe blanks with different crimping coefficients for different rates of deformation have been performed. Figure 4 shows the results of computer simulation of crimping with thickening for the coefficient $k = 0.7$.

![Figure 4. Workpieces during crimping with thickening: 1 – $V = 1$ mm/min; 2 – $V = 3$ mm/min; 3 – $V = 10$ mm/min;](image)
The results of the simulation have revealed that by local heating of the blank elements it is possible to form it with thickening at the ends of the given volume.

An increase in the deformation rate also has a positive effect on the upsetting of the end thickening. However, when the speed $V = 10$ mm/min is exceeded, transverse folds begin to form in the blank. It has been established that the speed $V = 3$ mm/min is rational from the point of view of forming the geometry of the products.

Figure 5 shows the results of computer simulation of pipe blanks with different crimping coefficients at a deformation rate of $V = 3$ mm/min.

![Figure 5. Workpieces during crimping with thickening: 1 – $k = 0.6$; 2 – $k = 0.7$; 3 – $k = 0.8$](image)

It was found that the selected rate of deformation with a change in the coefficient $k$ позволяет реализацию обжима труб без образования складок. However, it should be noted that at lower degrees of forming, the metal thickening at the ends is smaller. It was revealed that to provide the required end thickening, an increase in speed up to 10 mm/min at $k = 0.8$ and up to 6 mm/min at $k = 0.7$.

Figure 6 shows the results of the simulation of crimping of pipe blanks with different taper angles of the tool at the strain rate $V = 3$ mm/min and the coefficient $k = 0.7$.

![Figure 6. Workpieces during crimping with thickening: 1 – $\alpha = 10^\circ$; 2 – $\alpha = 15^\circ$; 3 – $\alpha = 20^\circ$](image)
It was revealed that with the same degree of forming \((k = 0.7)\) a decrease in the taper angle leads to a shortage of metal at the ends of the workpiece. In the investigated range of taper angles at \(\alpha = 10^\circ\) metal practically does not flow into the cavity for the formation of thickenings. Thus, with a decrease in the taper angle of the die to \(\alpha = 10^\circ\) it is required to increase the speed up to 30 mm/min.

The next stage of the process under study is the formation of thickenings on the upper (crimped) end of the semi-finished product. The scheme of this operation is shown in Fig. 1, b. This process involves the upsetting of the free part of the wall of the semi-finished product. During the simulation, the rates of deformation were established, which ensure a uniform flow of metal. They are \(1 - 2\) mm/min for the deformation under isothermal conditions.

The power characteristics of the process under study were established. Figure 7 shows the dependence of the change in forces in the deforming elements of the tool during the operation for different taper angles of the tool. The diagram is conventionally divided into 2 parts. The first part is crimping with thickening at the bottom. The second one is the thickening of the upper part.

![Figure 7. \(P, H\) plotted versus \(h\): 1 – \(\alpha = 10^\circ\); 2 – \(\alpha = 15^\circ\); 3 – \(\alpha = 20^\circ\)](image)

Figure 7. \(P, H\) plotted versus \(h\): 1 – \(\alpha = 10^\circ\); 2 – \(\alpha = 15^\circ\); 3 – \(\alpha = 20^\circ\)

Figure 8 shows the dependence of the change in deformation forces on the speed of the tool for different crimping coefficients.

![Figure 8. \(P, H\) plotted versus \(V\), mm/min: 1 – \(k = 0.6\); 2 – \(k = 0.7\); 3 – \(k = 0.8\)](image)

Figure 8. \(P, H\) plotted versus \(V\), mm/min: 1 – \(k = 0.6\); 2 – \(k = 0.7\); 3 – \(k = 0.8\)

Figures 7 and 8 demonstrate that an increase in the speed of the tool from 1 to 100 mm/min leads to an increase in the forces of the investigated punching process by more than 10 times. An increase in the crimping coefficient leads to a decrease in forces on the deforming tool by \(80 - 90\%\). An increase
in the taper angle of the tool from $\alpha = 10^\circ$ to $\alpha = 15^\circ$ leads to a decrease in forces by 10%. An increase in the taper angle of the tool from $\alpha = 15^\circ$ to $\alpha = 20^\circ$ leads to an increase in forces by 35 – 40%. Conventionally, the deformation process can be divided into four stages: crimping and thickening of the bottom part, which is divided into three stages (a smooth increase in forces, their fall and a sharp increase in deformation forces) and the stage of the upper thickening. The first three stages correspond to a non-stationary stage, which corresponds to a smooth growth of forces and the achievement of the first maximum. Further, the stationary crimping stage begins, which is characterized by a decrease in forces. And then the third stage starts, at which the upper wall of the semi-finished product is formed. At this stage, the thinning of the wall occurs due to the gap that is smaller than the wall thickness at this point. This stage is characterized by maximum strength. In the third stage, the forces for different taper angles are balanced.

**Conclusion**

It was found that during the process under study, the speed has a significant effect on both the power modes and the course of the investigated combined stamping process. A range of deformation rates has been established, which makes it possible to ensure the manufacture of products without loss of stability during deformation and minimum power loads on tools and equipment. It was revealed that the rational speed for the simultaneous crimping and thickening lies within the range of 3 – 10 mm/min, depending on the degree of deformation and the geometry of the tool.

**References**

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