Research of annealing mode for high accuracy stamped parts production from titanium alloy 83Ti-5Al-5Cr-5Mo after tooling

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Abstract. The aim of the work is to solve question of accuracy increase in tolled and annealed parts made from forged rod of titanium alloy. Plate pieces were cut from cross-section, annealed at 800°C during 1, 2, 3, 4 and 5 hours. The criterion combining minimum bending radius and spring back angle was found. This criterion shows the maximum values after tooling and annealing for 3 hours.

1. Introduction
Alloy 83Ti-5Al-5Cr-5Mo is used for manufacturing of high-load parts and constructions, which work for long periods of time at the temperatures of up to 350 - 400 °C (loaded components of airframes, wings, forged products, control system components, fastening pieces, e.g. eye bolts) [1]. These products are complex and require the obtaining high-accuracy of dimensions. Such products are manufactured from ingots by means of forging, stamping and finishing up of final dimensions with the use of tooling [2]. In the process of manufacturing of such products different operations of heat treatment are applied, including stress- relief annealing and mechanical hardening.

State Standard19807-91 [3] sets forth the grades of titanium alloys, intended for production of semi-finished products (sheets, bands, strips, rods, tubes, forged products and stamping billets) by means of plastic straining. Billets in the form of rods are used for manufacturing of parts for the aviation industry. According to the State Standard 26492-85 [4] the rods are manufactured without heat treatment (hot-rolled). In turn, the billets undergo the heat treatment (annealing or quenching and ageing). After annealing the material becomes highly ductile and weak. Cutting modes are chosen on the basis of the properties of the material. These properties, in their turn, are determined by the heat treatment mode. The process of mechanical treatment is accompanied by heating in the cutting area. This heating results in the structural changes of the material [5]. Such changes lead to the change of geometry of finished products. That is why additional calibration operations (fitting) may be required after tooling. Flat elements of parts are subjected to fitting by means of bending. For implementation of bending and fitting modes it is necessary to know the most appropriate heat treatment (annealing) modes, that ensure manufacturing of high accuracy products.

Finding out the cutting and fitting modes is based on the range of properties (maximum strength, yield strength, impact strength, minimum radius of bend, spring-back ratio, etc.) [6, 7]. These properties may change depending on the modes of deformational processing and heat treatment, demonstrating different tendencies: as a rule, after annealing viscosity increases, but strength, hardness and rigidity decrease [8, 9]. Consequently, there is no decisive criterion for choosing the temperature or duration of
annealing. The temperature of annealing is chosen depending on the grade of material or the alloying diagram. The duration of annealing depends on the size of the product, temperature and speed of heating [10]. Heating and structural transformations processes proceed slowly in massive elements of products and quickly in thin elements. This different speed of transformations leads to inhomogeneity of the cross-sectional structure of the product [11].

In order to determine the most practical annealing modes of products made of the alloy 83TI-5AL-5CR-5MO it is necessary to find out the criterion, that comprises technological properties and that would definitely determine the best combination of properties. The above-mentioned criterion can be useful after tooling and annealing before fitting.

2. Materials and methods

Samples with dimensions 2x10x30 mm were cut from the rod made of the alloy 83TI-5AL-5CR-5MO by the electro erosion cutting, which ensures the stability of structure and properties of the initial billet. In accordance to the State Standard 90013-, the alloy has the following chemical composition: 78.485…86.6 mass.% Ti (base element), 4.4…5.9 mass.% Al, 0.5…1.5 mass.% Fe, up to 0.1 mass.% C, up to 0.15 mass.% Si, 0.5…2 mass.% Cr, 4…5.5 mass.% Mo, 4…5.5 mass.% V, less than 0.05 mass.% N, less than 0.3 mass.% Zr, less than 0.2 mass.% O, less than 0.015 mass.% H.

After cutting the samples were subjected to bending in the tool die with the apex angle of 90° and spherical radius of 10 mm. After bending the samples were annealed at the temperature of 800 °C for the period of 1, 2, 3, 4 and 5 hours.

Geometry changes of the samples were determined on the basis of the change of the angle between the flanges of the billets after annealing. The measurements were carried out with the help of the software product COMPASS-3D. The scanned samples were used for measuring the expansion angles before and after annealing.

Then the samples were again subjected to deformation/strain until crack appearing. The radius at the billet apex was measured in order to determine the geometry change (The measurements were carried out with the help of the software product COMPASS-2D). The measurement principle is shown in figure 1.

Minimum radius of bend was calculated according to the formulae (1).

\[
\begin{align*}
    r_{\text{min}} &= \frac{r_{\text{mes}}}{t}, \\
    \text{(1)}
\end{align*}
\]

where \( r_{\text{mes}} \) - radius measured on the sample, mm; \( t \) - thickness of the sample, in our case \( t = 2 \) mm.

The spring-back ratio was calculated according to the formulae (2).

\[
\gamma = \frac{\gamma_{\text{ann}} - \gamma_{\text{init}}}{\gamma_{\text{init}}},
\]

where \( \gamma_{\text{ann}} \) - flanges expansion angle, measured on the sample after annealing, grad, \( \gamma_{\text{init}} \) - die apex angle, grad, in our case \( \gamma_{\text{init}} = 90^\circ \).

![Figure 1. Radius of bend measurement scheme](image-url)
3. Results

The found dependence $r_{\text{min}}$ from the annealing duration is shown in the figure 2.

![Figure 2. Dependence $r_{\text{min}}$ from the annealing duration](image)

The diagram shows the least value of the radius of bend hat equals 1.5, was obtained after annealing for the period of 4 hours. The minimal radius of bend ($r_{\text{min}}$) may be obtained without formation of a crack. Consequently, the lesser this indicator, the more effective is the conducting of bending operations, and the more exact are the obtained spherical radii of reinforcing ribs. That means that in order to conduct fitting it is necessary to perform preliminary annealing of the billet for the period of 4 hours.

Figure 3 shows the dependence of the spring-back ratio from the annealing duration. It can be seen that the diagram is non-monotonic and there are 2 minimums and 1 maximum value. Minimums are observed in respect of 2 and 4 hours of annealing (0.18 and 0.14 respectively). In this case it is impossible to definitely determine the optimal duration of annealing, because in case annealing is performed for the period of 2 hours, the high value of the minimal radius of bend is observed, and it equals 3 (figure 2).

![Figure 3. Dependence of the spring-back ratio from the annealing duration](image)
In order to find out the optimal annealing duration it is necessary to take into account both indicators that demonstrate the best fitness and suitability of the material for bending operations at their minimum values. For this purpose, the composite indicator of fitness of pressed/stamped and annealed products for fitting by means of bending was developed. This indicator is represented in the formulae (3).

\[ k_{\text{bend}} = \frac{1}{r_{\text{min}} \cdot \gamma}, \]  

where \( r_{\text{min}} \) - minimum radius of bend, \( \gamma \) - spring-back ratio.

While both indicators are non-dimensional, \( k_{\text{bend}} \) will also be non-dimensional. Analyzing the structure of the formulae, the lesser the denominator, i.e. the values of \( r_{\text{min}} \) and \( \gamma \), the higher is the indicator \( k_{\text{bend}} \). That is why maximum values of \( k_{\text{bend}} \) suggest the best fitness of finished products to bending operations within fitting. Dependence of \( k_{\text{bend}} \) from the annealing duration is shown in the figure 4.

The diagram shows that the composite indicator, combining the spring-back ratio and minimum radius of bend reaches its maximum value in case of exposure to annealing for the period of 4 hours.

Microstructural analysis of the deformation zone shows that annealing during 1 hour doesn't lead to any significant change in the size of the grain. And in case of exposure to annealing during 2 hours some equiaxial grains were observed on the background of elongated grains. This indicates the beginning of primary recrystallization. Annealing for the period of 3 hours leads to obtaining the most fine-grained structure that may cause the increase of the spring-back ratio. Annealing for the period of 4 hours leads to a non-material grain coarsening, but the grain structure retains its homogeneity. After annealing for the period of 5 hours, the structure is characterized with the presence of some coarse equiaxial grains on the background of small grains that suggests the beginning of secondary recrystallization.

![Figure 4. Dependence of \( k_{\text{bend}} \) from the period of annealing](image)

4. Conclusions

1. Dependence of minimum radius of bend from the period of annealing shows that the most favorable mode of annealing of titanium alloy 83TI-5AL-5CR-5MO + parts is heating to the temperature of 800 °C with the period of exposure to annealing amounting to 4 hours after tooling before fitting by bending. In these conditions the minimum radius of bend with the value of 1.5 is reached.
2. Dependence of spring-back ratio from the period of annealing reaches minimum values in case of two variants of annealing: 0.18 in case of 2 hours and 0.14 in case of 4 hours.

3. The developed criterion shows, that the most favorable combination of both indicators is observed in case annealing takes place for the period of 4 hours.

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