

Study of the Ti-5Al-5Mo-5V-1Cr-1Fe titanium alloy grain structure uniformity after bending and annealing

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Abstract. The uniform grain structure of titanium alloys is required to enhance the product manufacturability and precision. For the research, flat blanks cut out of the BT-22 titanium alloy forged bar were used. Bending tests with the subsequent annealing were carried out at the temperature of 800°C during 1–5 h. The grain size change and its uniformity depending on the annealing duration were analysed. The possibility of obtaining the uniform fine-grained structure after deformation and annealing for 4 hours was established.

1. Introduction

The stability of the manufacturing and machining process for metal alloy parts depends on the continuity and uniformity of the grain structure [1, 2]. Recently, titanium alloys have become increasingly applicable in the deformed condition owing to the developments connected with the thermal and deformation processing technologies [3]. When comparing between a cast and the deformed structure and the structure after the selective laser sintering of powder metallic materials [4], the deformed structure appears to be more advantageous. Such defects as porosity, non-uniformity of grains, sweating can be observed in the cast structure, while porosity, cracks, lack of penetration are characteristic of the selective laser sintering [5-8]. The structural change of the deformed semi-finished products as well as provision of the necessary structure depend on the coordinated combination of the deformation and thermal processing conditions [9, 10].

This work is aimed at analysing the grain structure uniformity in bending of forged Ti-5Al-5Mo-5V-1Cr-1Fe titanium-alloy blanks with the subsequent annealing at the temperature of 800 °C and the duration of 1, 2, 3, 4 and 5 hours.

2. Methods and materials

Samples with the dimensions of 2x10x30 mm were cut out of the bar (AMTU 451-67) using the electroerosion cutting method. The chemical composition of the alloy according to GOST 90013-81 [11] is given in table 1.

After cutting out, the samples were subjected to the bend deformation in the tool-making die with the angle at the vertex of about 90 ° and the rounding radius of 10 mm. After bending, the samples were annealed at the temperature of 800 ° C for 1, 2, 3, 4 and 5 h [12, 13].



Table 1. The chemical composition of Ti-5Al-5Mo-5V-1Cr-1Fe

Element' wt. %											
Fe	C	Si	Cr	Mo	V	N	Ti	Al	Zr	O	H
0.5 – 1.5	Up to 0.1	Up to 0.15	0.5 – 2	4 – 5.5	4 – 5.5	Up to 0.05	78.485 – 86.6	4.4 – 5.9	Up to 0.3	Up to 0.2	Up to 0.015

Later, microsections were manufactured of the samples obtained. Etching was performed using the following mixture: 180 ml of H₂O, 180 ml of HCl, 120 ml of HNO₃, 30 ml of HF. The duration of etching was 1-2 min; washing was carried out using running water followed by drying with filter paper. After etching, the microstructure was analysed using the metallographic METAM LV-32 tool-maker microscope. After photographing the microstructure, the uniformity of the grain structure was evaluated. To this end, 10 adjacent grains were detected in the figure along with measuring their smallest and largest size (figure 1).

**Figure 1.** The microstructure of a sample annealed for 5 h, and the grain selection and size measurement pattern.

Then, using the Microsoft Excel features, the maximum and the minimum values of the average grain size as well as their standard deviation were determined. Based on the received data, the number of intervals and the pitch were calculated. After that, the probability density distribution graphs for the grain size were built. As a result, the probability density vs the medium-size interval graph was obtained (figure 2).

Using the obtained data, the variety of the grain size was calculated using the following formula:

$$\beta = \frac{\Delta d_{gr}}{d_{prob} \cdot P},$$

where Δd_{gr} is the half-height grain size change, d_{prob} – the most probable grain size, P – the probability value.

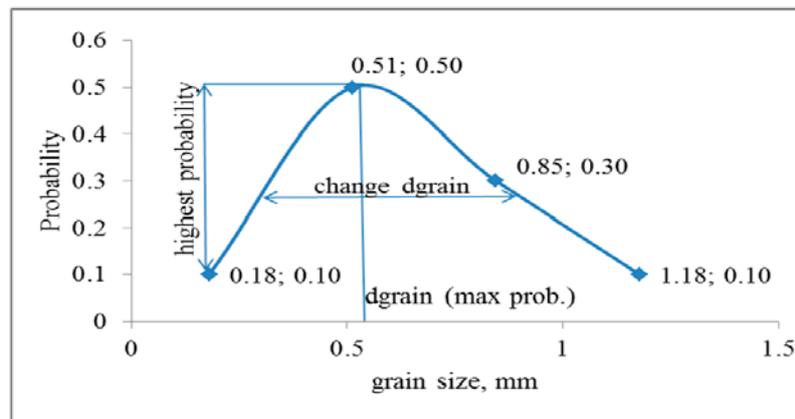


Figure 2. The probability density vs the interval for the sample annealed for 5 h

3. Results and discussion

The diagram of the grain size and grain structure non-uniformity vs annealing time is given in figure 3.

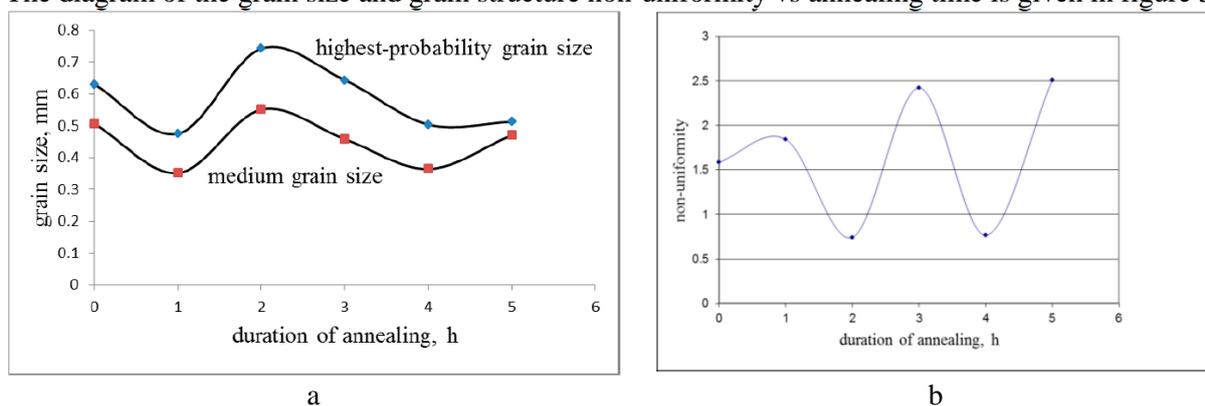


Figure 3. Grain structure change dependency: a – grain size, b – non-uniformity

Medium and highest-probability grain sizes have a similar nature of changes with the increased annealing duration. At the initial annealing stage, a minor grain structure size reduction takes place followed by the increase after the 2-hour holding. Further holding time extension results in the grain structure size reduction, which reaches the minimum after 4-hour holding. Then, a minor grain size increase is observed.

The non-uniformity and annealing time graph has a wavy form of changing. The change is insufficient within the interval from 0 to 1 h, an approximate two-fold non-uniformity reduction occurs within the interval of 2 h. The non-uniformity increases 3 times within the interval of 2-3 h; then it decreases 3.3 times after 4 h again, and increases 3 times for 5 h.

As a rule, the grain structure uniformity change is connected with the recrystallization processes. The data provided by the sources [14-16] indicate that the recrystallization threshold of titanium alloys largely depends on the extent of the preceding deformation. Before the beginning of recrystallization all the processes connected with the structure change take place inside grains, therefore its grain size and uniformity shall not change. The reduced non-uniformity may be connected with polygonal cells appearing inside the grains, which may be observed as particular grains.

Formation of new equiaxed grains on the background of a deformed structure shall result in the grain size variety, which is seen in figure 3 with the holding time of 2 h and more. Annealing for 3 h resulted in the highest grain structure non-uniformity, which becomes minimal after 4 h of holding. This may evidence the initial recrystallization completion. Holding during annealing for 5 h increases

the grain structure non-uniformity again, which may represent a secondary recrystallization manifestation.

Rebuilding of the grain structure may cause changes of the residual macro- and microstresses. As we see from figure 1, 6-8 grains fit within the plate thickness of 1 mm, which is indicative of a rather large grain, and the effect of recrystallization on both residual micro- and macro- stress. Change of residual microstress, represented in the study [12], shows that the annealing lasting for up to 3 hours at the temperature of 800 °C causes the increase of the residual compression stress both in the tension and compression zone. Increasing the holding time up to 4 h results in the decreased compressing microstress. This may result from the growth of new non-deformed grains, which reduces the moving stress for the grain boundary movement. Macrostress increases with holding within 2 to 3 h, which is supposed to be connected with the beginning of initial recrystallization. The holding time extended further will not cause critical changes in macrostresses at the beginning of the subsequent recrystallization stage as well; furthermore, the change of the grain structure non-uniformity allows evaluating time intervals of each stage.

4. Conclusions

Evaluating the non-uniformity allowed establishing the sequence of structural changes occurring during the annealing. This study allowed establishing the fact that when annealing the Ti-5Al-5Mo-5V-1Cr-1Fe titanium alloy at the temperature of 800 °C during 4 h, the smallest grain size, which possesses the minimal non-uniformity, is formed, i.e. the most preferable structure is created.

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