

**Conference Paper**

# Investigation of the Mechanism of Precipitation of the Ti<sub>3</sub>Al in Two-Phase Titanium-Aluminium Alloy

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## Abstract

Changes in the formation processes of the ordered Ti<sub>3</sub>Al phase ( $\alpha_2$  phase) was studied depending on the heat treatment in the Ti – Al alloy. It was shown that high-temperature treatment in a single-phase  $\alpha$ -region, followed by supercooling at different temperatures, leads to a more active release and growth of dispersed particles than after preliminary processing from the  $\beta$ -region.

**Keywords:** titanium alloys, intermetallics, ordered phases

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## 1. Introduction

Modern high-temperature industrial titanium alloys usually contain aluminum in an amount limited to 8... 9 wt%. This limitation is due to the formation of the Ti<sub>3</sub>Al phase ( $\alpha_2$ -phase) precipitated in alloys containing more than 6% Al. It is also known that the concentration of  $\beta$ -stabilizers can influence the formation of this phase. With their high content, the formation of  $\alpha_2$ -phase is possible with short exposure times during heat treatment, while at low concentrations a longer holding time is required. It is known that the Ti<sub>3</sub>Al phase precipitated in the alloy is ordered (structural type DO19). It can improve the characteristics of heat resistance while plastic properties are reduced due to blocking of dislocations by these particles [1, 2]. However, the effect on mechanical properties may depending on the transformation mechanism. Visco-plastic characteristics of the alloy are at a low level when dispersed particles of an ordered  $\alpha_2$ -phase are formed, which is realized as a heterogeneous transformation by the mechanism of nucleation and growth. While the formation of a two-phase structure by a homogeneous mechanism with the formation of antiphase boundaries (APB) does not lead to a significant decrease in characteristics [3].

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According to the data of [4], an alloy containing 25.2 at% Al should be disordered in the quenched state, and according to the results of differential thermal analysis, only after heating above 617 °C does the ordering  $\alpha \rightarrow \alpha_2$  occur. The influence of the chemical composition of the alloy and heat treatment on the ordering processes in alloys of the Ti-Al system was studied in [5]. It was established that dispersed ordered particles of the  $\alpha_2$ -phase were formed in alloys that contain from 12 to 21 at.% Al. Whereas antiphase boundaries were observed after aging in alloys from 21 to 25 at.% Al.

## 2. Material and Methods

The study was conducted on samples of model cast alloys Ti-17 at.% Al and Ti-26 at.% Al. Ingots weighing 3 kg were subjected to homogenization annealing in a vacuum furnace at a temperature of 1200 °C for 1 hour, followed by cooling in an oven. Heat treatment of samples consisted in heating to 950 °C during 1 hour. Quenching into water after high-temperature treatment was carried out for part of the samples, followed by aging at temperatures of 500 and 650 °C with exposures up to 300 h.

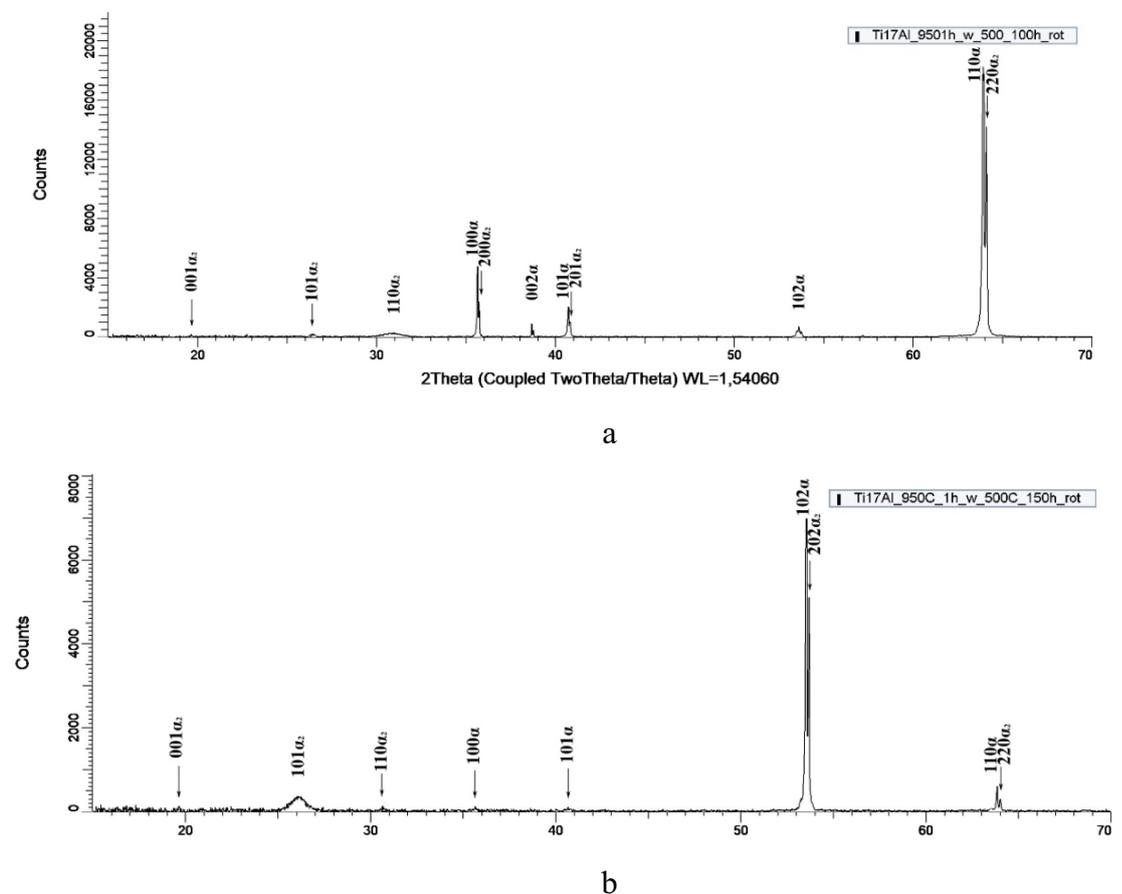
The main research methods were transmission and scanning electron microscopy, performed on Jeol 200CX microscopes with an accelerating voltage of 160 kV, as well as JEM-2100C and JSM6490, equipped with energy dispersive composition analyzers. X-ray diffraction analysis was performed on a Bruker D8 Advance diffractometer in Cu K $\alpha$  radiation.

## 3. Experimental Procedure

According to previous studies [6], fragments of antiphase boundaries are observed in the structure during cooling of the Ti26Al alloy with 1200 C, and  $\alpha_2$ -phase reflections are present on the electron diffraction patterns.  $\alpha_2$ -phase reflexes are observed on electron diffraction patterns after quenching an alloy with a lower aluminum content of Ti17Al from both a temperature of 1200 C from a single-phase  $\beta$ -region and from a temperature of 950 C from a single-phase  $\alpha$ -region.

The results [7] showed that quenching from single-phase  $\beta$ -region before aging samples of the Ti17Al alloy leads to the formation of dispersed particles of the  $\alpha_2$  phase of about 5-10 nm. These particles are formed by the mechanism of nucleation and growth. Antiphase boundaries of the thermal type (homogeneous mechanism) were observed only after carrying out heat treatment on samples of a Ti26Al alloy containing 26 at. % Al. Isothermal holding after high-temperature treatment at 950 °C in the single-phase

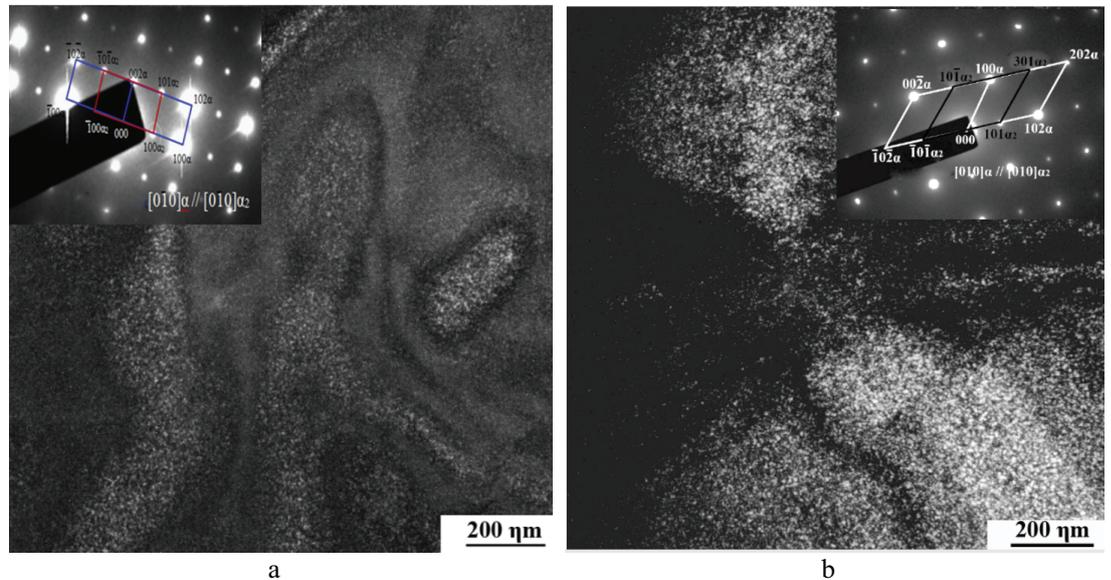
$\alpha$ -region led to similar results for an alloy containing 17 at. % Al [7]. At the same time, the homogeneous mechanism ordering was observed in separate volumes after low-temperature treatment of experimental titanium alloys of the Ti-Al-Sn-Zr-Mo-Si system, containing up to 12.5 at. % Al, according to the data of [8]. Particles with sizes from 25 to 200 nm were obtained in the article [9] during long-term aging of an alloy containing 15 at. %, at temperatures of 450-750 °C with a delay of up to 500 hours. Aging time of the quenched samples at a temperature of 500 °C was increased to 100 and 150 hours for further study. As a result of evaluating the results of X-ray phase analysis, it was found that after these heat treatments a two-phase structure ( $\alpha + \alpha_2$ ) is formed (Fig. 1).



**Figure 1:** Diffraction patterns of the samples after heating to 950 °C with an exposure of 1 hour and subsequent aging at 500 °C with an exposure: a - 100 hours; b - 150 hours.

Brighter reflections of the  $\alpha_2$ -phase were observed on microelectron diffraction patterns after aging. The aging of the alloy for 100 hours leads to an increase in the number of dispersed particles of the  $\alpha_2$  phase (Fig. 2, a), but does not lead to a significant change in their size relative to the treatments carried out in previous work [7]. Subsequent heat treatment with quenching from 950 °C and aging at 500 °C with a duration of 150 hours

does not lead to a significant growth of  $\alpha_2$ -phase particles (Fig. 2, b). The average particle size after this treatment reaches 10-20 nm.

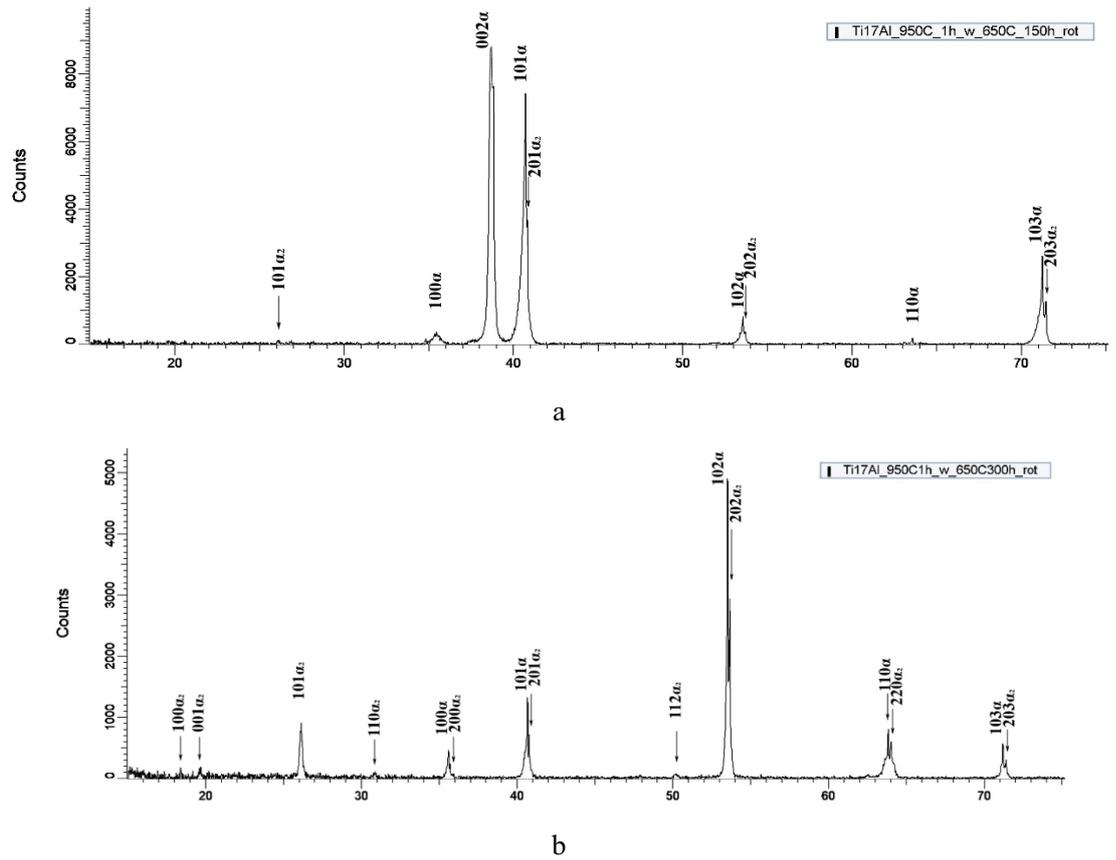


**Figure 2:** The microstructure of the alloy Ti17Al after high-temperature treatment at 950 ° C with an exposure of 1 hour and aging at 500 ° C with an exposure: a - 100 hours; b - 150 hours.

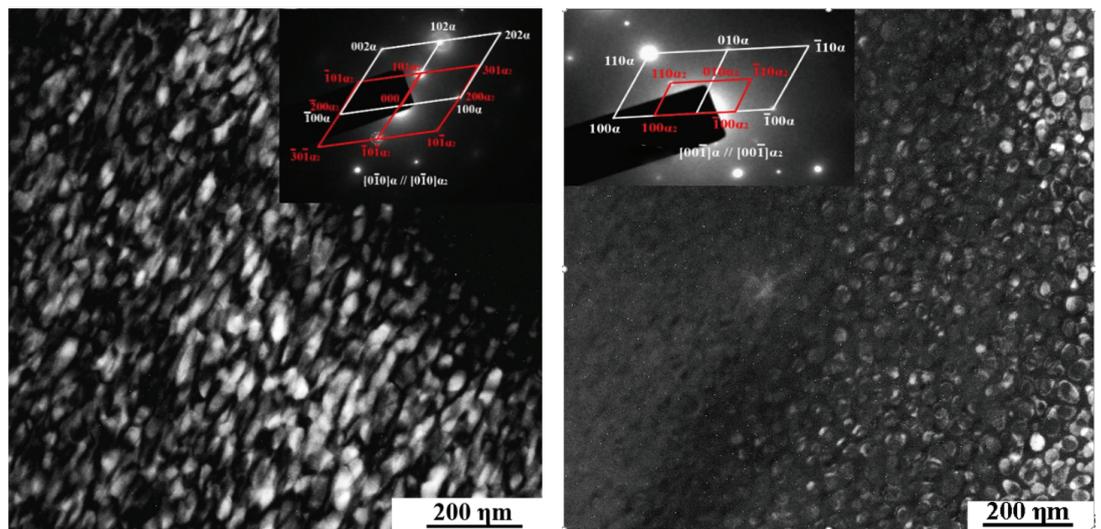
It was decided to increase the aging temperature of the alloy to 650 ° C and the exposure time to 150 and 300 hours at the next stage of the study. According to the results of X-ray structural phase analysis, it can be seen that the volume fraction of the  $\alpha_2$ -phase increases with increasing exposure time at a given temperature (Fig. 3).

An electron microscopic study showed that the electron diffraction patterns showed clear, bright reflections of the ordered Ti3Al phase on the samples after aging for 300 hours. However, particles of the ordered  $\alpha_2$  phase were still observed in the obtained dark-field images. The sizes of these particles have increased in comparison with the previous treatments and are approximately equal 40-50 nm (Fig.4, a).

From this it follows that carrying out treatments with both supercooling and aging after quenching for the Ti17Al alloy leads to the formation of only dispersed particles of the  $\alpha_2$  phase in the structure, which means the transformation under the mechanism of nucleation and growth, and, consequently, the formation of a two-phase structure by heterogeneous transformation. However, carrying out several similar heat treatments of a single-phase Ti26Al alloy leads to the formation of antiphase boundaries of the thermal type, and, consequently, the passage of the transformation by a homogeneous mechanism.



**Figure 3:** Diffraction patterns of the samples after heating to 950 ° C with a holding time of 1 hour and subsequent aging at 650 ° C with a holding time: a - 150 hours; b - 300 hours.



**Figure 4:** The microstructure of the alloy Ti17Al after high temperature treatment at 950 ° C with an exposure of 1 hour and aging at 650 ° C with an exposure of 300 hours.

## 4. Conclusions

It was established that in the Ti-17 at.% Al alloy, the formation of particles of the ordered  $\alpha_2$  phase in the process of aging after quenching or processing with supercooling in the temperature range of 400... 650 ° C occurs as a phase transformation of nucleation and growth. The size of the forming particles increases with increasing exposure time and temperature. Signs of homogeneous  $\alpha \rightarrow \alpha_2$  transformation not detected.

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