

**Conference Paper**

# Effect of Carbon Content on the Structure and Mechanical Properties of Ti-10V-2Fe-3Al Alloy

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## Abstract

The effect of carbon content on microstructure and mechanical properties of the transition ( $\alpha+\beta$ )-titanium alloy Ti-10V-2Fe-3Al in a heat-strengthened state was studied. It was established that with the increase of carbon content in the alloy up to the limit of its solubility in a solid solution, the strength of the alloy increases, the plastic characteristics decrease. When the solubility limit of carbon in a solid solution in an alloy is exceeded, the appearance of titanium-based carbide particles was observed, while the strength of the alloy somewhat decreases, due to the decrease of the effect of solid-solution hardening from the elements present in the alloy, which are partially transferred from the solid solution to the titanium-based carbide particles.

**Keywords:** titanium alloys, titanium carbides, mechanical properties, hardening heat treatment.

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## 1. Introduction

The titanium alloy Ti – 10V – 2Fe – 3Al has been developed for the manufacture of high-strength elements to replace steel, which gives a significant weight gain. Since 1980s the alloy has been widely used in aircraft industry for manufacture of landing gear assemblies and loaded airframe elements [1]. Due to the high content of  $\beta$ -stabilizers, the alloy has significantly lower  $\beta$ -transus temperature in comparison with the widely used Ti6Al4V alloy, which allows it to be deformed at lower temperatures and with less effort than Ti6Al4V [2]. Hardening heat treatment of the Ti-10V-2Fe-3Al alloy is used to obtain the final complex of mechanical properties. The alloy strength can be changed in a wide range from 1000 to 1350 MPa by changing the temperature of aging [3]. The mechanical properties of the alloy, in addition, are influenced by a large number

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of structural parameters, which are determined by the composition of the alloy and the thermomechanical parameters of its processing.

In a number of studies it was found that the addition of carbon to titanium alloys has a positive effect on a number of their properties. In particular, carbon reduces the size of initial  $\beta$ -grain [4, 5], accelerates aging dynamic, increases strength and creep resistance [6], increases the hardening effect during aging [7], complicates the formation of grain boundary  $\alpha$ -phase and stimulates more uniform decomposition during aging [8, 9]. With a high carbon content, the formed titanium carbides can partially bind oxygen in the alloy, helping to reduce the oxygen content near the grain boundaries and thereby reduce the probability of grain-boundary embrittlement during aging [10]. However, titanium carbide is known to have high elastic modulus and low ductility, which can negatively affects to the number of mechanical properties of the alloy [11]. Therefore, the questions concerning the determination of the carbon solubility limit in various titanium alloys and the influence of titanium carbides on physical-mechanical properties of the alloys are actual. The purpose of this work was to determine the limiting carbon solubility at the Ti–10V–2Fe–3Al titanium alloy and to study the effect of carbon content on the structure and mechanical properties of the alloy.

## 2. Materials and Methods

The investigated material was 22 mm rods of Ti – 10V – 2Fe – 3Al alloy produced by PSC «VSMPO-AVISMA Corporation». The investigation of five Ti–10V–2Fe–3Al alloy compositions with different carbon content, aluminum and molybdenum structural equivalents, calculated by the formulas from the handbook [12], which are presented in Table 1, was carried out. After rolling, a hardening heat treatment (STA) was performed: water quenching from the temperature below  $\beta$ -transus with the subsequent aging at the temperature of 530 °C.

TABLE 1: Chemical composition of investigated Ti–10V–2Fe–3Al alloys.

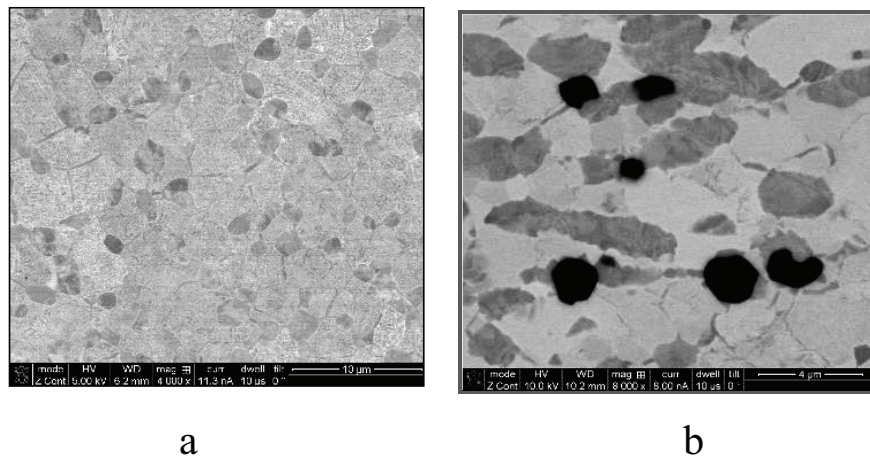
| Alloy | C, [wt.%] | O, [wt.%] | Al <sub>str.eq.</sub> | Mo <sub>str.eq.</sub> |
|-------|-----------|-----------|-----------------------|-----------------------|
| S1    | 0,008     | 0,11      | 4,3                   | 11,10                 |
| S2    | 0,022     | 0,10      | 4,37                  | 11,07                 |
| S3    | 0,031     | 0,10      | 4,44                  | 10,99                 |
| S4    | 0,034     | 0,10      | 4,49                  | 11,30                 |
| S5    | 0,063     | 0,10      | 4,73                  | 11,27                 |

Mechanical properties of the alloy were determined by tensile testing at room temperature on a Zwick tensile testing machine in accordance with ASTM-E8. Microstructure

and fractographic research of the samples fractures were carried out by Quanta 3D FEG electron microscope with EDAX Genesis 2000 detector.

### 3. Results of Research and Their Discussion

The microstructure of the Ti – 10V – 2Fe – 3Al alloy with the minimum and maximum aluminum equivalent (Al.eq.) after rolling is shown in Fig. 1.

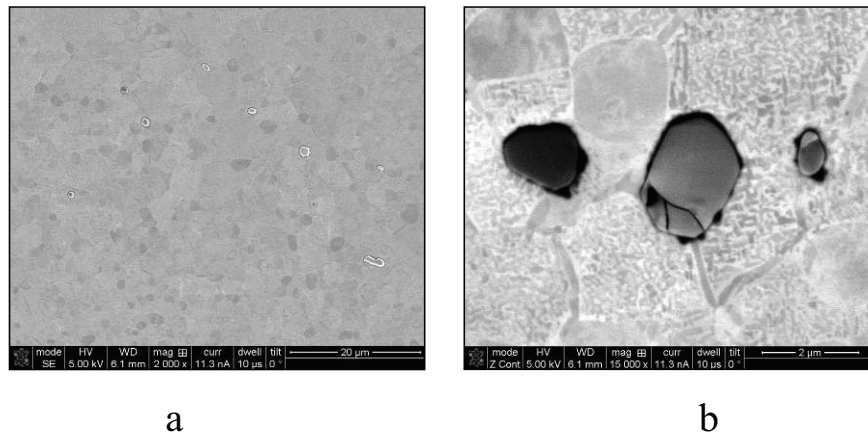


**Figure 1:** Microstructure of Ti – 10V – 2Fe – 3Al alloy: a - alloy S1; b - alloy S5.

The globular primary  $\alpha$ -phase and fine secondary  $\alpha$ -phase in the  $\beta$ -matrix, which is formed upon cooling, are observed in the structure of samples. The equiaxed particles of third phase similar to the globules of the primary  $\alpha$ -phase, but with a darker contrast, were found in the structure of the alloy with the maximum carbon content in the mode of backscattered electrons (Fig. 1). Such dark contrast indicates a greater content of elements with a smaller atomic number in this particles compared to the  $\alpha$ -phase. It should also be noted that dark equiaxed particles are observed both on the primary  $\alpha$ -phase and in the  $\beta$ -matrix.

The microstructure of samples after STA was shown in Fig. 2. The particles of the third phase observed after hot rolling are remained. Aging contributes to the uniform segregation of dispersed secondary  $\alpha$ -particles in the body of  $\beta$ -grains (Fig. 2 a). The chemical composition of particles of the third phase, obtained by the method of X-ray microanalysis, is presented at Table 2. A comparative analysis of the elements content in the particle and matrix spectra allows us to attribute these particles to titanium based carbide. According to the literature data, this is the type  $\text{TiC}_x$  carbide ( $x = 0.3 \pm 1$ ). The lower carbon content, which was obtained in the analyzed particle, compared to the stoichiometry of carbide  $\text{TiC}_x$ , is obviously due to its relatively small size (less than 2 micrometers), which results in an underestimated carbon content due to the partial

“highlight” of the matrix during X-ray microanalysis. Such kind particles in samples with lower carbon content did not found.



**Figure 2:** The microstructure of the sample of Ti–10V–2Fe–3Al alloy with 0.063 wt. % of carbon.

**TABLE 2:** The chemical composition (EDS) of Ti–10V–2Fe–3Al sample with 0.063 wt. % of carbon.

| Chemical element | Analysis area, composition [wt. %] and ([at. %]) |             |
|------------------|--|-------------|
|                  | The third phase particle                         | Base metal  |
| C                | 4.8 (16.6)                                       | -(-)        |
| Al               | 1.53 (2.35)                                      | 2.86 (5.01) |
| Ti               | 88.02 (76.46)                                    | 85.6 (84.4) |
| V                | 4.69 (3.83)                                      | 9.67 (8.97) |
| Fe               | 0.97 (0.73)                                      | 1.87 (1.58) |
| Total            | 100 (100)  | 100 (100)   |

The mechanical properties of alloy rods after STA are presented in Fig. 3. The yield strength increases from 1016 to 1095 MPa and the elongation decreases from 19 to 16 % with the increase in carbon content from 0.008 to 0.034 wt. %, With a carbon content of 0.063 wt. %, the yield strength was lower than at 0.034 wt. % of carbon, amounting to 1078 MPa, at a higher elongation of 17 %. We associate this behavior of properties during the formation of carbide particles with the transition of the part of alloying elements (Al, V, Fe) from solid solutions ( $\alpha$ ,  $\beta$ ) in the alloy to carbide and, accordingly, decrease in their contribution to the solid solution hardening. In addition, as noted above in work [10], during the formation of titanium-based carbide, it can partially bind oxygen impurity, contributing to a certain increase of ductility, which we also fixed.

As a result of the fractographic research of sample fracture, it has been established that fractures are viscous of a similar cup-cone type. The significant differences between the samples under the fractographic study were not found.

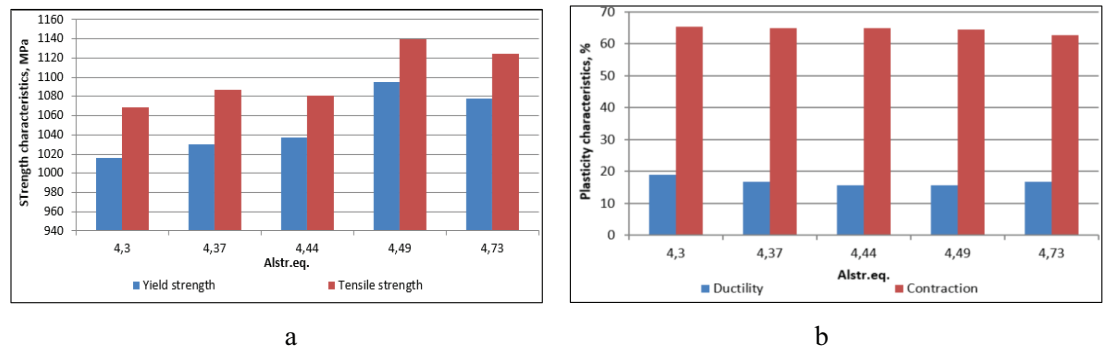


Figure 3: The dependence of Ti–10V–2Fe–3Al mechanical properties on the  $\alpha$ -stabilizers content.

## 4. Conclusion

The effect of different carbon content on microstructure and mechanical properties of Ti–10V–2Fe–3Al titanium alloy has been studied. According to the work results, the following conclusions were made:

1. Prior to the precipitation of the carbide phase the strength properties increase, and the plastic properties decrease with an increase in the carbon content from 0.008 to 0.034 wt. % in the alloy after the STA.
2. Precipitation of  $TiC_x$  titanium carbide and slight decrease in the strength properties is observed at the alloy with 0.063 wt. % of carbon content, which is associated with a decrease in the effect of solid solution hardening from the elements present in the alloy, which are partially transferred from the solid solution to the formed carbide particles.
3. After the deformation of the alloy in the ( $\alpha + \beta$ )-field, the carbide-phase particles have an equiaxial shape similar to the globular morphology of the primary  $\alpha$ -precipitates.
4. The presence of titanium carbides in the alloy does not change the specimens fracture character after tensile tests at heat strengthened state.

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