Materials Physics and Mechanics 39 (2018) 128-134 Received: November 1, 2017

RESISTANCE TO EROSIVE DESTRUCTION OF STEAM TURBINE BLADES FROM TITANIUM ALLOYS, THEIR STRUCTURE AND PHASE COMPOSITION

Nikolay A. Krylov, Margarita A. Skotnikova*, Galina V. Tsvetkova, Galina V. Ivanova

Peter the Great St. Petersburg Polytechnic University, Polytekhnicheskaya 29

195251, St. Petersburg, Russian Federation

*e-mail: skotnikova@mail.ru

Abstract. Using optical metallography, electron microscopy, X-ray analysis and X-ray microspectral analysis, we have developed a procedure for studying structural and phase transformations in the material of steam turbine blades from titanium alloy VT6 after technological treatments. An attempt was made establish a link between resistance to erosion destruction and structural and phase composition of titanium alloys.

Keywords: microhardness, phase composition, steam turbine blade, titanium alloy

I. Introduction

Titanium alloys keep a leading position in producing steam turbine blades. The unique combination of high specific strength and fracture toughness, corrosion resistance, and high resistance to shock loading (Figs. 1 and 2) defined their wide application in power engineering [1, 2].

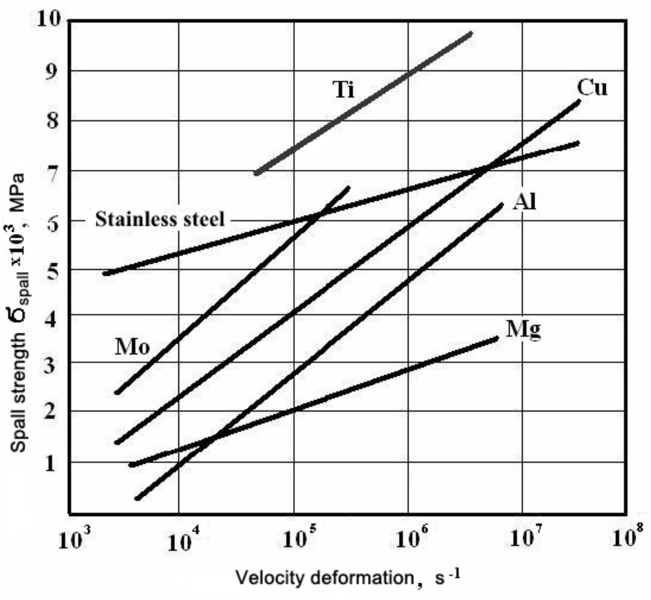

Fig. 1. Dependence of spall strength from velocity deformation for different metals

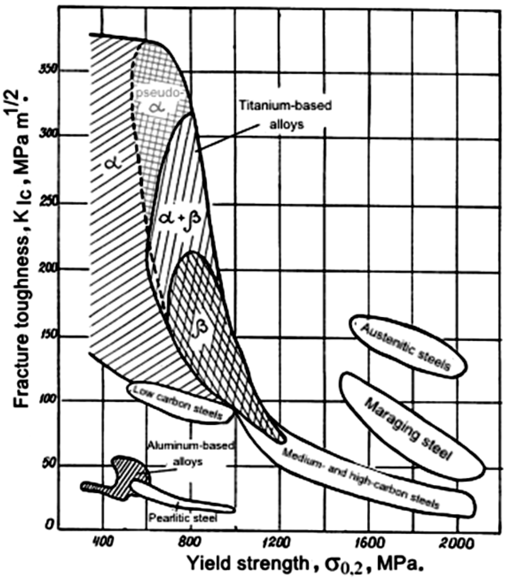

Fig. 2. Correlation of fracture toughness and yield strength of titanium alloys

http://dx.doi.org/10.18720/MPM.3912018_19

Two-phase titanium alloys found wide application in turbine construction due to opinion [3] that the largest resistance to the steam-drop exposure should have two-phase alloys with low internal stresses and high plastic properties. However, power engineering still has a problem of erosion damage of steam turbine blades because of drop impact of vapor particles at the rate of 150...600 m/s. A typical example of erosion destruction of steam turbine blades is shown in Fig. 3. To solve the problem, it is necessary find relation between the wear and structural-phase state of the surface and axial layers of blade material. On the basis of our investigations [4-8], the generalized kinetic diagram has been constructed (Fig. 4).

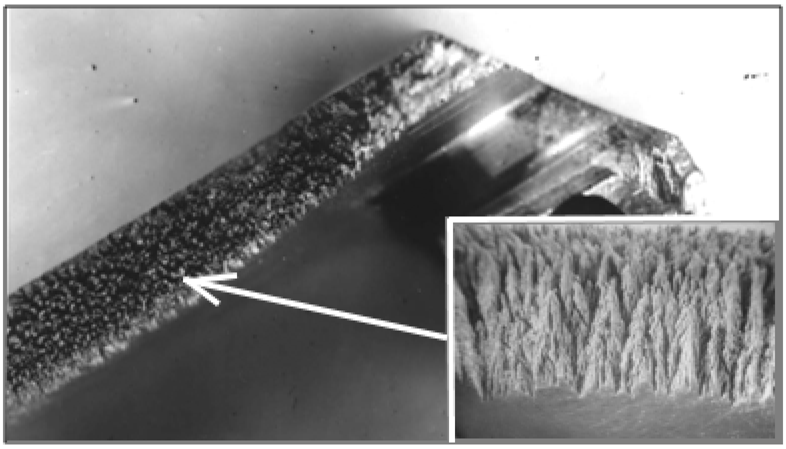

Fig. 3. Erosion destruction of steam turbine blades

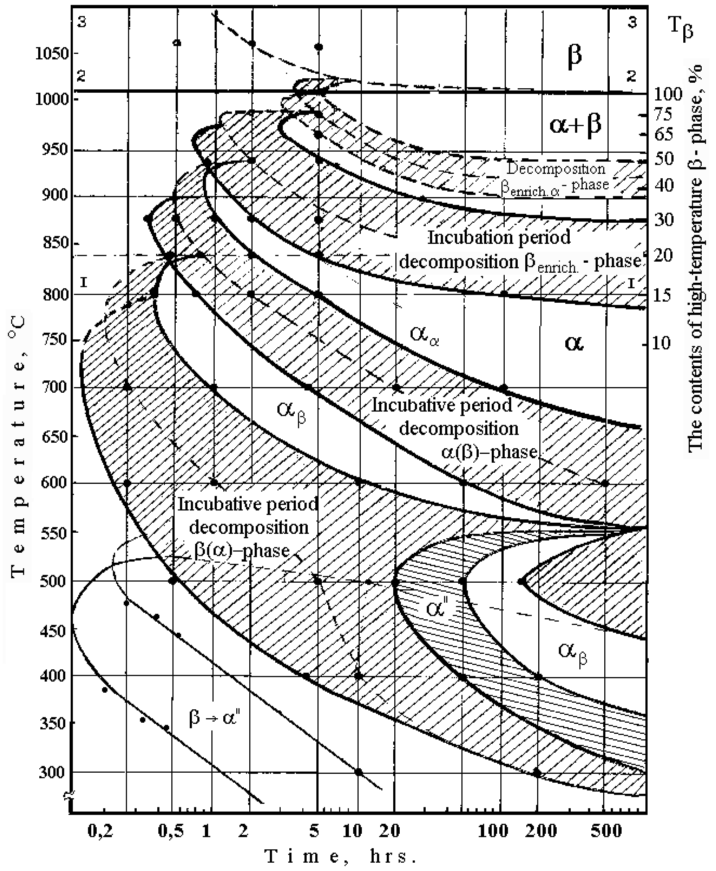

Fig. 4. Generalized kinetic diagram of structural and phase transformation of titanium alloys

We have found that the more nonequilibrium $\beta(\alpha)$- and $\alpha(\beta)$- solid solutions contain the same alloying elements; the lower the temperature of their many-stage decomposition, which takes more time. It is established that titanium blanks possess high technological properties in the temperature-time interval of two-phase (α+β)- region at temperatures corresponding to 50 − 50 content of high-temperature α- and β- phases (T_{50}), and near the transition temperature in the single-phase β- region (T_{75}).

In this contribution the object of research have been samples of steam turbine blades from two-phase titanium alloy VT6 (Ti-6Al-4V) after deformation in $\beta-$area and final deformation by stamping in $\alpha+\beta-$area near to temperatures T_{50} and T_{70}, which correspond to the first and second technology.

2. Structure and phase composition

Both stamping technology provide a bimodal structure of α-phase globular grains (α_I) and platelet-shaped grains ($\alpha_{I\ I}$), divided by layers of β_{II} –phases (Fig. 5). Electron microscopy shows that the boundaries of phase components (α_I, α_{II}, β_{II}) in the case of the first technology are much better relaxed (Fig. 6) due to dislocation appearance. For the second technology, there are less of curved extinction contours that indicate the presence of internal stresses.

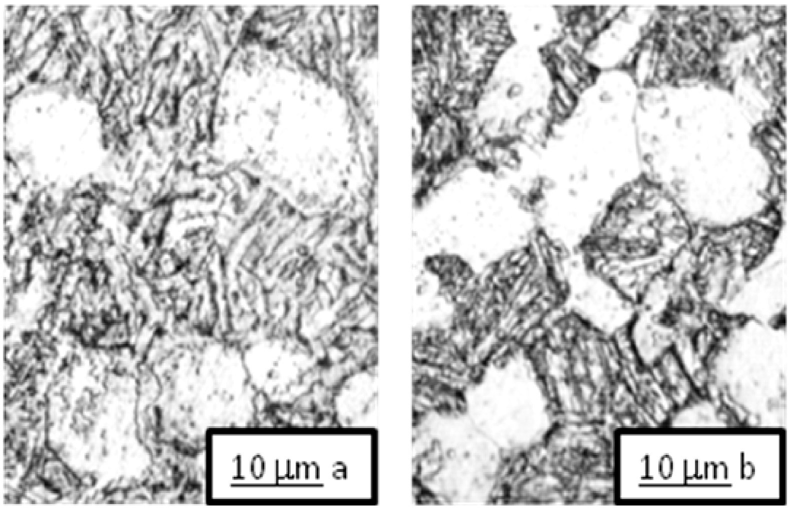

Fig. 5. Microstructure after stamping by first (a) and second (b) technology

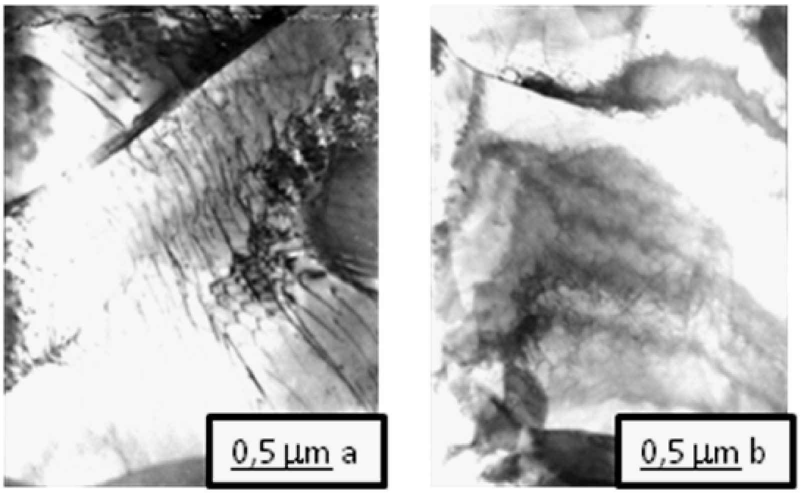

Fig. 6. Electron microscope structure after stamping by first (a) and second (b) technology

In the first technology case the plate width of α_{II}–phase is 3 times more and the interlayer width of β_{II}–phase is 8 times more than those of for the second technology, the lamellar size of (α_{II}+β_{II})–phases being a little more (Table 1). At low temperatures in the first case, there forms structure similar to Widmanstatten one. Such structure has higher fatigue strength than the martensite-like structure obtained by the second technology [9].

Table 1. Particles size of phase components of metal blades, fabricated on two technologies

Phase	Particle size, [µm] first technology	Particle size, [µm] second technology
α_I	15	12
α_{II}	2,2	0,7
β_{II}	0,8	0,1
$\alpha_{II}+\beta_{II}$	22	18

3. Distribution of alloying elements

In Table 2 the data obtained by X- ray microspectral analysis are presented. They show the contents of alloying elements (aluminum, vanadium) in separate phases. From the table we notice that for both technologies the secondary plates of α_{II} - phase have a chemical composition comparable with the average composition of alloy Ti-6AL-4V. However, the globular primary α_I - phase in the blades material fabricated by the first technology contains 0.6 % less vanadium and 1.3 % more aluminum, in comparison with the second one. Thin layers of the secondary β_{II} -phase are enriched with vanadium (β - stabilizer), but in the material obtained by the first technology β_{II} - phase has 1.3% more vanadium and 0.5% less aluminum than for the second technology. Such distribution of the alloying elements provides relative softness of β_{II} -phase layers and higher performance as compared with the second technology [10]. At the same time the distribution of alloying elements in different phases for one and the same technology is as follows: the globular primary α_I – phase, as compared with the plate α_{II} – phase, has 1.3% more aluminum and 2.2% less vanadium in the first case; 0.97% and 1.96% respectively in the second case.

Table 2. Contents of alloying elements in phases

Phase	Concentration [weight %] first technology		Concentration [weight %] second technology	
	AL	V	AL	V
α_I	7,30	1,35	6,97	2,04
α_{II}	6,01	3,60	5,68	4,21
β_{II}	4.14	9,64	4,61	8,28

Figure 7 shows a typical distribution of the alloying elements with a step of 0.5 microns. It is seen that the most non-uniform distribution has vanadium, being focused in β_{II}- phase. Its concentration can change from 1 up to 20 %. Aluminum is distributed more uniformly; however, its concentration changes from 3 up to 7 %.

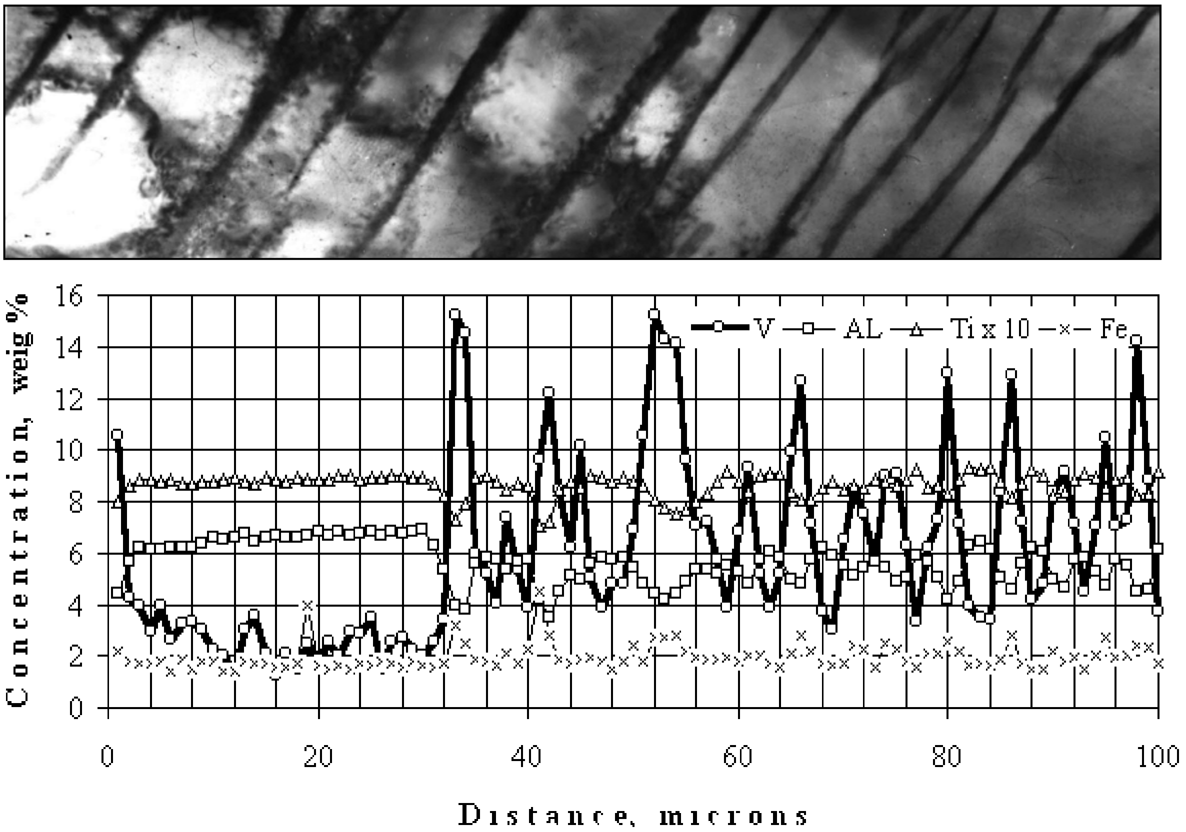

Fig. 7. Microstructure and distribution of alloying elements

4. Microhardness of phase components

In Table 3 the data of statistical treatment of microhardness measurements for separate phases are shown. It is seen that the microhardness is higher in the case of second technology what confirms the presence of internal stresses. It is necessary to stress that the first technology decreases the difference between the hardness of globular and lamellar structure. The blades material fabricated on both technologies had a bimodal structure. Probably, the strength balance of α_I- and (α_{II} + β_{II}) - structural fashions can guarantee high serviceability of a material under loading.

Table 3. Microhardness of phases in blades fabricated by two technologies

Phase	Microhardness [MPa] first technology	Microhardness [MPa] second technology
α_I	3550	3664
α_{II}	3830	4091
β_{II}	2584	3000
α_{II} +β_{II}	2999	3020

In Figure 8 correlation between microhardness and chemical composition of separate phases (α_I, α_{II}, β_{II}) in a condition of delivery is presented.

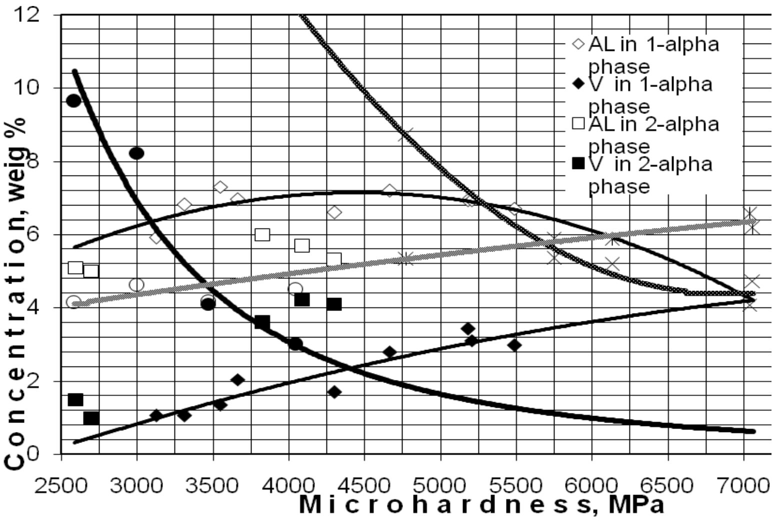

Fig. 8. Correlation between microhardness and chemical composition of separate phase

It should be noted that the microhardness increases with the growth of α-stabilizer, probably due to the formation α^{I} – martensite, and decreases with increasing amount of β stabilizing elements, leading to the formation α^{II} - martensite. This agrees with the fact mentioned above that in the first technology material there forms β -phase with a larger amount of β - stabilizing elements. Such distribution of vanadium gives lesser microhardness and greater softness of β_{II} - phase layers.

6. Conclusion and discussion

Blades of steam turbines fabricated from alloy VT6 by final stamping under two technological circuits had bimodal structure; the share of lamellar $(\alpha_{II}+\beta_{II})$-structure being 50…70 % prevails over that of globular α_I- structure, which is 30…50 %. For a crack it is more difficult to grow in $(\alpha_{II} + \beta_{II})$- lamellar structure because of braking by soft layers of β_{II}- phase, owing to it is compelled to change the trajectory, bending around globalized particles of α_I- phase. Thus operational properties of product material increase [9-11].

Alloy VT6 concerning to martensite class, in stable condition contains 10…18 % β- phase, which at sharp cooling turns into α^{I}- or α^{II}- martensite. However, $\beta \to \alpha^{II}$- transformation can take place even at room temperature. It is known, that plastic deformation accelerates decomposition of β-solid solution with formation of α^{II} - phase [12]. The subsequent ageing at temperatures 450…500 °C results in its decomposition and formation of α^{I} + (β) – phases. The phase transformation $\alpha^{II} \to \alpha^{I} + (\beta)$ leads to significant strengthening of the alloy. According to the generalized kinetic diagram (Fig. 4), the more β- phase contains β- stabilizing elements, the lower temperature and longer time is necessary for $\beta \to \alpha^{II}$- transformation.

References

[1] S.G. Fedotov, K.M. Konstantinov, *Titanium – New Constructional Material* (Mashgiz. Moscow 1987).

[2] G.I. Kannel, S.V. Razorenov, A.V. Utkin, *Shock-Wave Phenomena in Condensed Matter* (Janus, Moscow 1999).

[3] M.E. Deitch, G.F. Filippov, *Two-Phase Currents in Elements of the Heat Power Equipment* (Enegroatomizdat, Moscow 1987).

[4] M.A. Skotnikova, A.M. Parshin, Disintegration and chart of thermal treatment of titanium two-phase alloys // *Metallurgy and Heat Treatment of Metals* **1(7)** (1997) 31.

[5] M.A. Skotnikova, G.V. Tsvetkova, A.A. Lanina, N.A. Krylov, G.V. Ivanova, Structural and phase transformations in material of blades of steam turbines from titanium alloy after technological treatment // *Advances in Mechanical Engineering. Lecture Notes in Mechanical Engineering* **22(1)** (2015) 93.

[6] M.A. Skotnikova, S.S. Ushkov, Development of scientific principles for the choice of final heat treatment of two-phase hot-rolled semi-finished products from titanium alloys // *Progressive Materials and Technologies* **3** (1999) 91.

[7] M.A. Skotnikova, T.A. Chizhik, I.N. Tsybulina, A.A. Lanina, N.A. Krylov, Use of titanium alloys as shovel material of steam turbines // *Materials Science Questions* **51(3)** (2007) 61.

[8] M.A. Skotnikova, N.A. Krylov. E.K. Ivanov, G.V. Tsvetkova, Structural and phase transformation in material of steam turbines blades after high-speed mechanical effect // *Advances in Mechanical Engineering. Lecture Notes in Mechanical Engineering* **54** (2016) 159.

[9] Js. Park, H. Margolin // *Metallurgical Transaction A* **15(1)** (1984) 155.

[10] I. Holl, K. Khammond, In: *Proceedings of the Conference Titanium-77* (Moscow 1977).

[11] M.A. Skotnikova, T.A. Chizhik, A.S. Lisyansky, O.N. Simin, I.N. Tsybulina, A.A. Lanina, Study of working shovels of high power turbines with regard to structural and phase transformations in stampings from titanium alloy BT6 // *Metal Treatment* **54(6)** (2009) 12.

[12] V.N. Gridnev, O.M. Ivasishin, S.P. Oshkaderov, *Physical Bases of High-Rate Thermo-strengthening of Titanium Alloys* (Naukova Dumka, Kiev 1986).