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Structural and Phase Transformation in a Cold-Deformed Titanium Alloy During Aging

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Abstract

The change of structure, phase composition and properties during aging of VT22 (Ti-5Al-5Mo-5V-1Fe-1Cr) titanium alloy rods, pre-quenched from β- or (α+β)-region and cold deformed with different degrees of compression, were studied by such methods as SEM, XRD-analysis and microhardness measurement.

Keywords: titanium alloy, quenching, cold deformation, aging, phase transformation, structural transformation, microstructure, the morphology of phases, microhardness.

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1. Intorduction

VT22 (Ti-5Al-5Mo-5V-1Fe-1Cr) high strength titanium alloy is promising for use in heavy-duty structures of aerospace equipment such as the chassis, fuselage, wing of the aircraft, attaching parts such as power bolts due to high specific strength, viscosity, corrosion resistance, hardenability and high reliability during operation [1].

The effect of hardening during aging of (α+β)-titanium alloys depends on both the product decomposition dispersion of the β-metastable solid solution and the product decomposition distribution in the structure.

The use of cold plastic deformation between quenching and aging will lead to the formation of dislocations and other deformation defects in the structure. It makes possible to modify the nucleation of the α-phase during aging [2-6]. Thus, it allows improving the microstructure and increasing the complex of mechanical properties. In this regard, the aim of this research was to study the processes occurring during the aging of quenched and cold-deformed VT22 titanium alloy.

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2. Research Material and Methods

The material of the study was hot-rolled rods with a diameter of 15 mm made of industrial VT22 (Ti-5,52Al-4,94Mo-4,86V-1,11Fe-1,04Cr-0,11O (wt.%) titanium alloy, manufactured at VSMPO-AVISMA Corporation.

First, cylindrical rods billet (diameter of 15 mm and height of 15 mm) were heat treated in β-region at 950 °C (T_β+100 °C) or (α+β)-region at 830 °C (T_β–30 °C) for 1 hour and after quenched in water.

Then the quenched billets were cold deformed by compression along the rolling axis with different compression ratio ε. Deformation was performed on a hydraulic press with a force of 5 MN using the graphite lubricant.

At the end, quenched and cold-deformed billets were aged at 500, 550, 600 or 650 °C for 4 hour.

The study was conducted using the methods of XRD-analysis on x-ray diffractometer Bruker D8 Advance; SEM using the microscope Jeol JSM-6490LV with the microanalysis system Oxford Instruments Inca Energy 350. Microhardness analysis was carried out on microscope Neophot-21 using consoles for the microhardness at a load of 100 g.

3. Results and Discussion

According to the scanning electron microscopy decomposition of β-solid solution in quenched from (α+β)-region alloy during aging occurs with the formation of a secondary α-phase. Secondary α-phase morphology represents plate packages of several orientations in the one β-grain (fig. 1, a-d). The interplate distance rises with the increase of aging temperature from 500 to 650 °C due to the acceleration of diffusion processes during the growth of temperature, noted in the works [2, 7, 8].

The quenching from β-region compared to the quenching from (α+β)-region leads to the formation of a more ordered "zigzag" structure in aging with a large average size of α-plates (Fig. 2, a-d). This is due to the large recrystallized β-grain size.

By the method of XRD-analysis, it was found that an increase in the aging temperature from 500 to 650 °C firstly leads to a decrease in the α-phase line physical broadening from 0,71 to 0,46 and from 0,80 to 0,47 for alloys quenched from (α+β)- and β-region respectively, secondly it leads to the ratio of the *c/a* crystal lattice parameter of α-phase increase (Fig. 3, a)

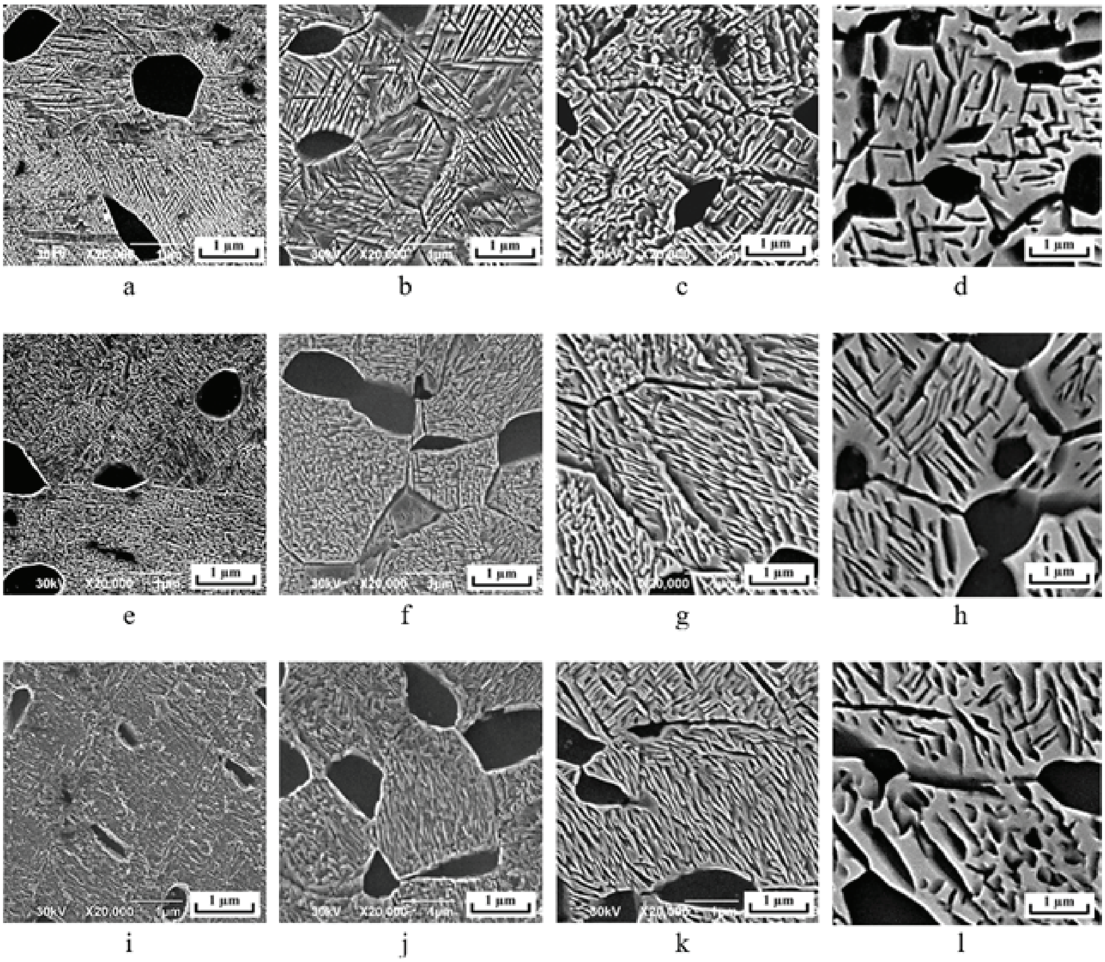

Figure 1: Microstructure of aged VT22 alloy, pre-quenched from (α+β)-region at 830 °C and cold-deformed by compression: a-d – compression degree of 0 %; e-h – compression degree of 6 %; i-l – compression degree of 14 %; a, e, i – aging temperature of 500 °C; b, f, j – aging temperature of 550 °C; c, g, k – aging temperature of 600 °C; d, h, l – aging temperature of 650 °C.

This indicates the formation of a less defective α-phase with a high content of aluminum at higher temperature of aging, which is consistent with the data of [1, 2, 7-9].

The volume fraction of the secondary α-phase decreases with the increase of the aging temperature, which leads to depletion of β-solid solution α-stabilizing elements and the increase of the β-phase lattice period (Fig. 3, b).

The formation of larger α-phase plates and the increase of β-solid solution volume fraction in the structure with the increase of aging temperature in alloys quenched both from 830 °C and 950 °C, contributes to a decrease in microhardness from 5830 to 4370 MPa and from 5830 to 4580 MPa, respectively (Fig. 4). However, the overall level of microhardness of an alloy quenched from 950 °C is higher than of an alloy quenched from 830 °C, due to the greater volume fraction of the secondary α-precipitates during aging.

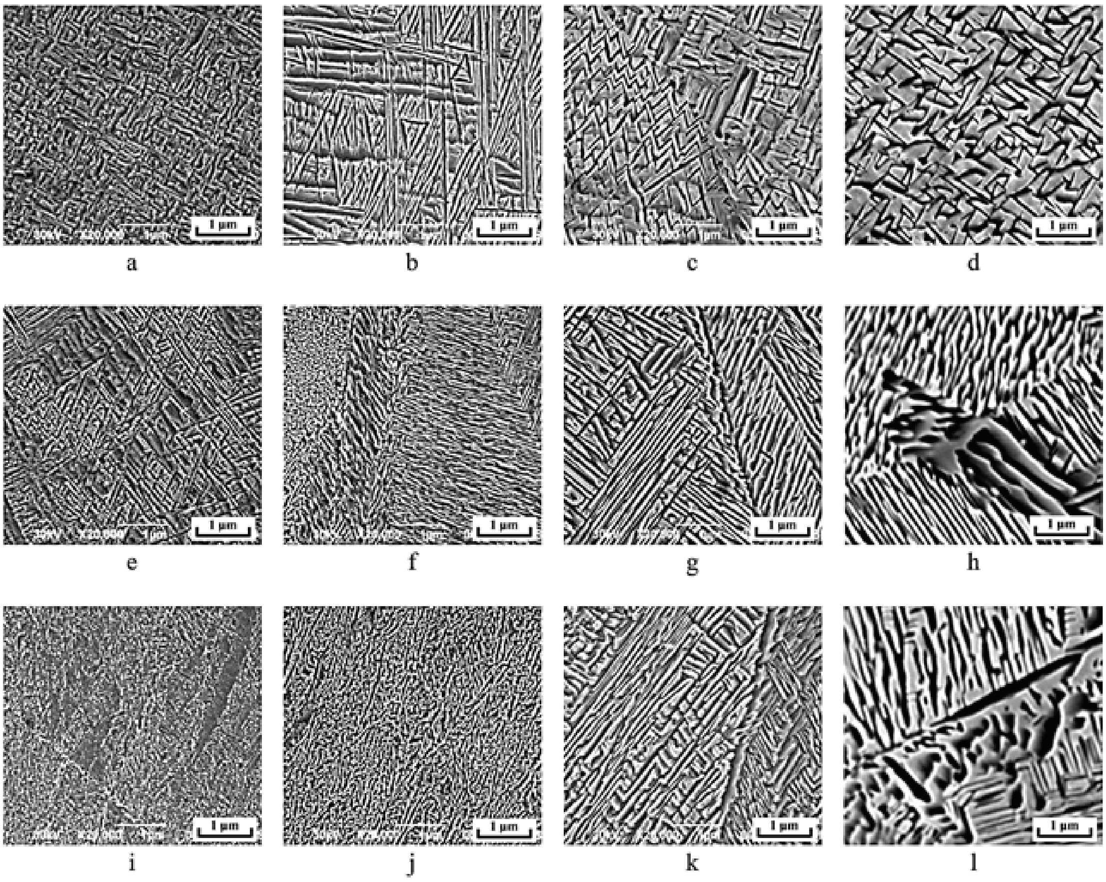

Figure 2: Microstructure of aged VT22 alloy, pre-quenched from β-region at 950 ∘C and cold-deformed by compression: a-d – compression degrees of 0 %; e-h – compression degree of 6 %; i-l – compression degree of 16 %; a, e, i – aging temperature of 500 ∘C; b, f, j – aging temperature of 550 ∘C; c, g, k – aging temperature of 600 ∘C; d, h, l – aging temperature of 650 ∘C.

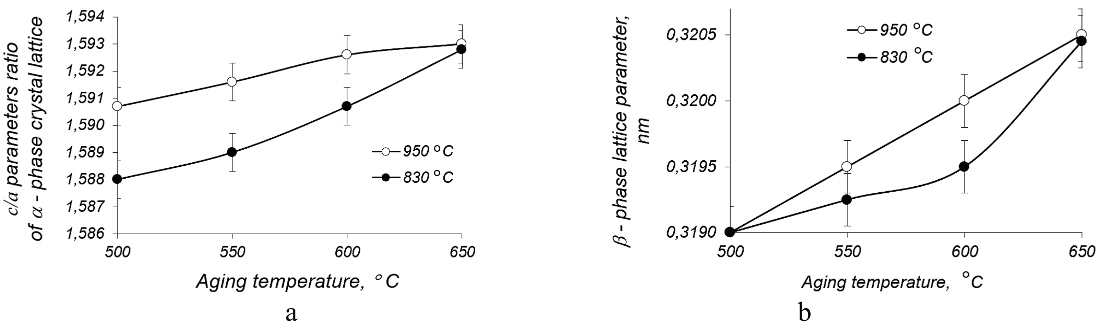

Figure 3: *c/a* parameters ratio of α-phase crystal lattice and β-phase lattice parameter depending on the aging temperature of VT22 alloy at various quenching temperatures.

It was shown in previous work [10], that the phase and structural transformations of the alloy that take place during the cold deformation by compression are realized in the following sequence:

–structural transformations: easy (single) slip (ε ∼ 2 %); multiple slip (ε ∼ 6 %); the formation of a cellular structure (ε ∼ 16 %); the formation of deformation twins (ε ∼

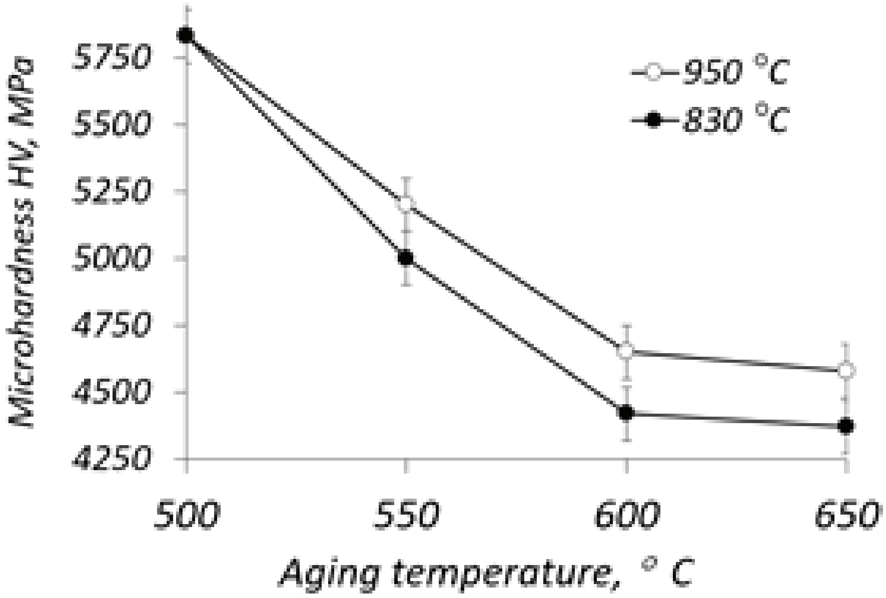

Figure 4: Microhardness of VT22 alloy depending on the aging temperature at various quenching temperatures.

23 % and greater). The formation of twins during deformation was also observed in the ordered β-matrix [11];

–phase transformations: the formation of the τ phase at the degrees of deformation 6 % and greater; the formation of α”-martensite at the deformation degrees of 14-16 % and greater. The phases of shear origin, i.e., the τ phase and the α”-martensite, are similar. Such phases represent regions in the β-grains, which do not have clear interfaces with the matrix in the form of bands with an enhanced density of dislocations having characteristic orientations, which indicates that the α”-martensite may inherit its morphology from the τ phase as a result of the τ(β)→α” transformation.

Below we consider how this structure influence on the aging processes.

The morphology of the particle precipitation during the aging in the quenched from β- and (α+β)- region of the alloy with cold plastic deformation of compression degrees up to 2 % retained as in an undeformed state (Fig. 1, a-d and Fig. 2, a-d).

The rod compression degree of 6 % and 14-16 % leads to the decrease of α-plates emerging during the aging (Fig. 1, e-l and Fig. 2, e-l). This is due to the rise of the crystalline structure defects density of β-solid solution, an increase in the length of the interphase boundaries during the formation of deformation-induced phases (τ, α”) during the cold plastic deformation, thus, the rise of α-phase origin places quantity. The precipitated plates are not always straight; often they are curved and have a wrong shape (Fig. 1, e-l and Fig. 2, e-l), moreover, the interplate distance at the coincided compression levels quenched alloys slightly rises during the increase of quenching temperature from 830 (Fig. 1, e-l) to 950 °C (Fig. 2, e-l).

The growth of *c/a* crystal lattice ratio of α-phase saves during the rise of the aging temperature (Fig. 3, a) as well as after the cold plastic deformation (Fig. 5).

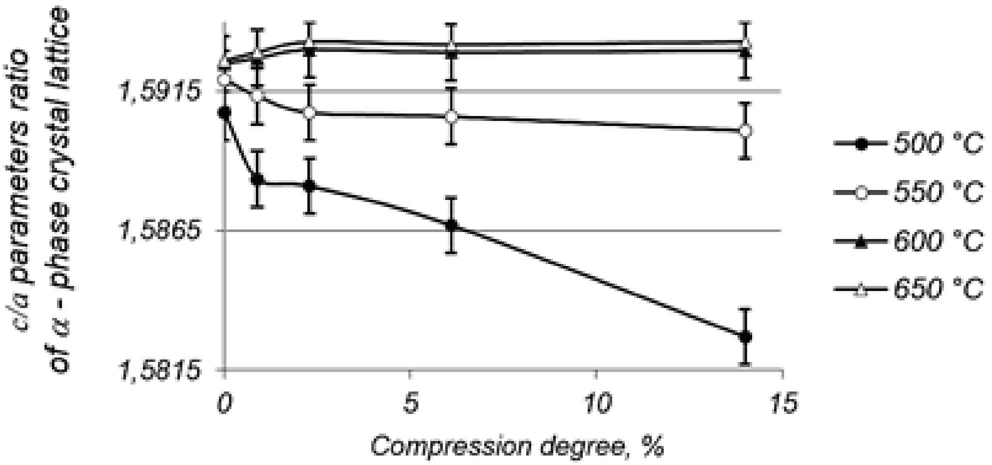

Figure 5: *c/a* ratio of the α-phase lattice after the aging at the different temperatures depending on the compression degree of rods quenched from (α+β)-region.

The fixed level of *c/a* steady changes depending on the deformation degree. It is related to the different completeness of β-solid solution decomposition and the deformation-induced phases formation.

Uptrend of β-phase crystal lattice periods of cold deformed rods with different compression degrees during the increase of the aging temperature saves as well as the described quenched and aged rods. This means that the 4-hour exposure chosen for aging ensures a sufficiently complete process of decomposition in both quenched and deformed alloys with the formation of the (α+β)-structure with a close to equilibrium composition of the phases.

The microhardness behavior depends on the aging temperature and the quenching temperature depending on the compression degree (Fig. 6).

Some decrease of the durometric characteristics during the rise of the compression degree is related to the coagulation processes of precipitating α-particles in a high-deformed alloys at the aging temperatures of 600 °C and 650 °C. A softening due to the α-particles coagulation is less significant because of lower temperature (at the aging temperature of 550 °). It is compensated by the β-matrix hardening due to previous cold plastic deformation. This causes the constant level of microhardness at the different compression degrees. During the aging at 500 °C strength increases at low deformation degrees due to the β-matrix deformation hardening, and the yield on a constant level at higher degrees is due to the same reasons as during aging at 550 °C. The general level

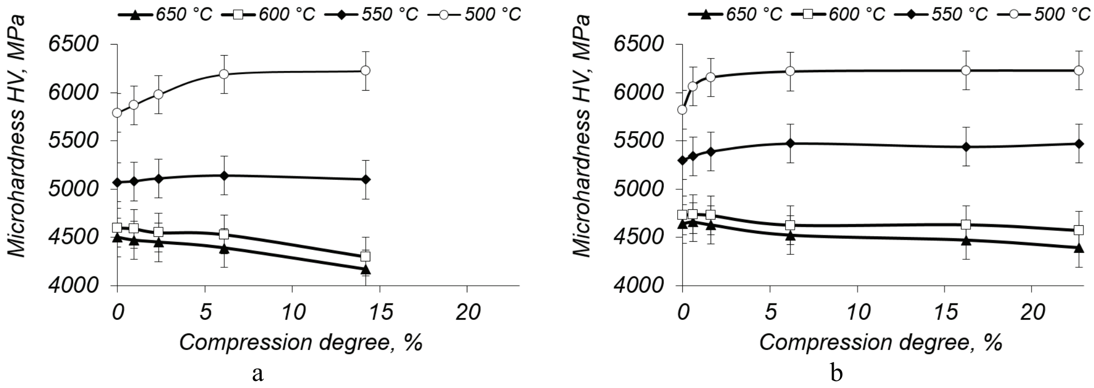

Figure 6: Microhardness after aging at the different temperatures depending on cold plastic deformation degrees of VT22 alloy, pre-quenched from temperatures of: a – 830 °C; b – 950 °C.

of the microhardness during the aging after quenching from 950 °C is higher than after the quenching from 830 °C, due to the larger volume fraction of secondary α-particles because of the absence of primary α-particles.

4. Conclusion

Thus, it is shown that the increase in the quenching temperature of hot-rolled in (α+β)-region rods of VT22 titanium alloy from 830 °C to 950 °C contributes to obtaining higher durometric characteristics of the quenched and cold-deformed alloys at the same aging temperatures due to the larger volume fraction of decomposition products.

The cold plastic deformation before the aging leads to the change of α-precipitation morphology at the deformation degrees larger than 6 %. The behavior of durometric characteristics change with the deformation degree at the aging is determined by the development of the alloy softening processes, due to the development of coagulation processes of the second phase particles, and hardening as a result of deformation hardening and the intensification of the α-particles precipitation.

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