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The effect of phase state on damping capacity in Ti–5Al–5Mo–5V

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The internal friction and Young's modulus behavior at function temperature in the range from 78 K to 300 K were studied in Ti–5Al–5Mo–5V alloy. The changing of quenching temperature regulated the phase composition. The internal friction peaks at 140–160 K were observed. The peak parameters were found to be sensitive to phase composition. The nature of maxima was discussed. The significant decrease of Young's modulus was observed in monophase β alloy after quenching at temperature 900°C.

Исследовано влияние фазового состава Ti–5Al–5Mo–5V сплава на температурные зависимости внутреннего трения и модуля Юнга в диапазоне 78–300 К. Фазовый состав сплава регулировался путем изменения температуры нагрева под закалку. Установлено существование максимума при 140–160 К, параметры которого зависят от фазового состава сплава. Проведен анализ процессов, отвечающих за формирование пика. Обнаружено значительное снижение модуля в однофазном β-сплаве после закалки от 900°C.

Titan alloy (Ti–5Al–5Mo–5V) was developed for aviation industry as a deformable heat-resistant and structurally stable substance, which is able to function at high mechanic and thermal influence [1, 2]. Exposed to various influences, the material can realize a variety of structural and phase states. Today the possibilities of controlling the structure and properties of the alloy by thermomechanic treatment are far from being exhausted. The processes that take place at such controlling and their effect on the mechanic characteristics of the material are not studied in full measure. One of the informative methods for nondestructive check of materials structure and properties is the method of internal friction [3, 4]. The measuring of ultrasound wave absorption in relation to the frequency, the oscillations amplitude and other parameters allow studying the material properties in the process of heating, deforming or phase transformation. This article is devoted to studying the thermomechanic processing effect on the structure and properties of titan alloy Ti-5Al-5Mo-5V by internal friction (IF).

Before the samples preparation, the material was annealed at 900°C for 1 h, the temperature being higher than phase $\beta \rightarrow \alpha + \beta$ transition (for this alloy it is 880°C [1]). As a result of annealing, β-state BCC (bulk-centered cubik) lattice with grain size about 100 μm is formed in all the volume of the material. For the internal friction studies, cylindrical samples 3 mm in diameter and of half-wave length (24–35 mm) were prepared. The length was selected experimentally. After 2 h of heating at the temperatures from 600°C to 1200°C with different exposures (in the open air and in vacuum ampoules), the samples were water-quenched. The samples were deformed at uniaxial tension. The hydroextrusion deformation was done with special equipment, developed in our institute. The phase structure was determined with X-ray analysis. In the samples prepared the relaxation spec-

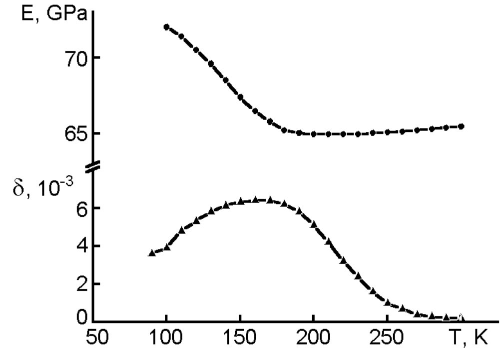

Fig. 1. The temperature dependencies of internal friction and Young's modulus for monophase 100 % β alloy (after quenching heating to 900°C).

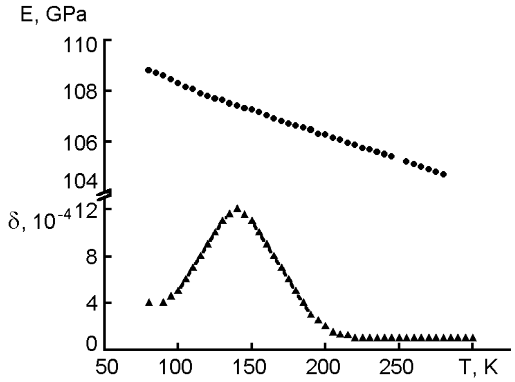

Fig. 2. The temperature dependencies of internal friction and Young's modulus for two-phase 40 % β + 60 % α alloy (after heating to 600°C).

trum of internal friction δ(T) in the temperature span 78–300 K was studied. The simultaneous measurements of δ scintillations logarithmic decrement and normal elasticity modulus E were measured by the method of double composite vibrator [4, 5] in 70–100 kHz frequency range in the region of amplitude-independent internal friction for the longitudinal oscillations mode with the amplitude $\varepsilon = 10^{-7}$. The composite vibrator was situated in the vacuum chamber of KG-100 cryostat at the pressure less than 10^{-3} mm of mercury. The rate of heating and cooling of the samples was no more than 0.5 K/min. The temperature and logarithmic decrement of fading measurement error was ~ 5 %.

As a result of internal friction δ(T) temperature dependencies in Ti–5Al–5Mo–5V alloy, a stable maximum of internal friction is found in temperature range 140–160 K (Figs. 1, 2), the position T_m and height δ_m of which depend on temperature as well as on the annealing conditions of the samples. The increase of hardening heat temperature from 600°C to 900°C leads to the displacement of maximum temperature T_m from 140 K to 160 K, the height of the peak δ_m increasing five times. The further increase of the heating to 1200°C leads to the decrease of peak T_m temperature from 160 K to 150 K and a small decrease of peak δ_m height.

The value of damping also depends on the defect structure of the alloy. The effects of the uniaxial deformation and hydroextrusion on the logarithmic decrement and Young's modulus at room temperature are shown in Fig. 3.

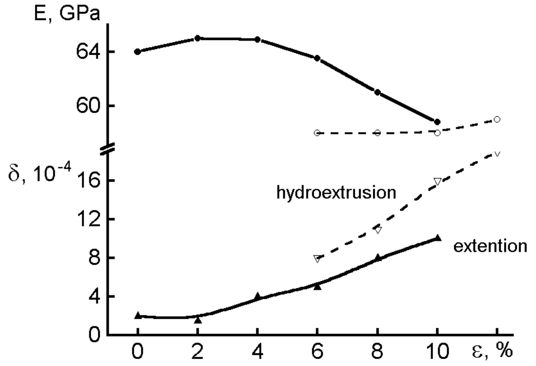

Fig. 3. The effect of deformation on the damping decrement and Young's modulus (measured at room temperature).

The data on the heating temperature influence on the damping value δ_{300} and Young's modulus E_{300} at room temperature are represented in Fig. 4. The temperature increasing to 900°C, the modulus becomes smaller, and its further behavior depends on the conditions of the experiment. Vacuum annealing doesn't influence the modulus, while annealing in the open air leads to the increase of the modulus. The value of internal friction δ_{300} monotonously increases with the heating temperature.

So, now we shall discuss the results. To find out the nature of the peak observed, additional experiments for studying the dependence of δ(T) at other frequencies of ultrasound oscillations were held. A displacement of IF peak towards higher temperatures at the increase of oscillations frequency was discovered. This confirms the relaxation origin of the peak. The active energy of activation, calculated by Max-Vert formula, is $U = 0.23$ eV and corresponds to the deformation mechanism, con-

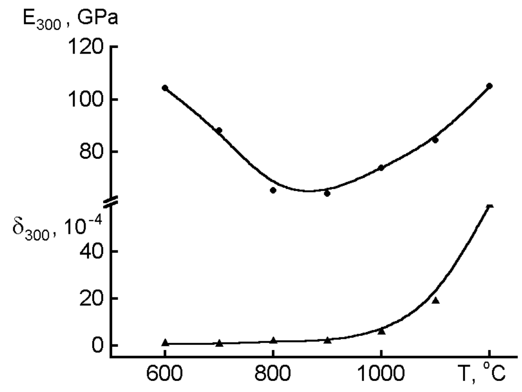

Fig. 4. The effect of quenching temperature on the damping decrement and Young's modulus (measured at room temperature).

nected with the point defects caused by a large number of alloying elements [3].

But IF maximum observed is much wider than Debye peak, which implies that there are some other processes in the given temperature interval. In our view, at the same time with the defects relaxation, a thermal phase transformation (PT) $\beta\leftrightarrow\alpha''$ takes place by martensite mechanism in the peak range at 140–160 K. The probability of $\beta\leftrightarrow\alpha''$ transformation is indicated by the results of works [6–8], in which this transformation is observed at room temperature and initiated by deformation. This means that the martensite point T_f is lower than room temperature for metastable monophase β alloy, and the cooling of the alloy at IF measuring leads to martensite transformation of thermal origin.

The parameters of IF maximum depend on the quenching temperature due to different phase compositions of the alloy and the peculiarities of martensite transformations at the phases with various metastability degrees. According to the phase diagram, at room temperatures the titan alloy is Ti–5Al–5Mo–5V two-phase $\alpha + \beta$ alloy, the temperature of $\beta + \alpha$ transformation being 880°C. After the heating followed by quenching from 900°C temperature one-phase β state BCC is realized. This state is more metastable than two-phase state. After hardening heat at $T <$ 880°C, two-phase $\beta + \alpha$ state is formed in the material. Here the amount of precipitate hexagonal α phase is the larger, the lower the annealing temperature is. In the two-phase alloy the β phase metastability degree decreases due to β phase enrichment in alloying elements at α phase particles precipitating. The correlation between the β phase amount and the parameters of IF peak allows us to set up a correspondence between the temperature of the maximum T_m and the one of the martensite transition T_f. The lowering of T_m temperature in two-phase alloy can also be explained. For a more stable β phase in the two-phase alloy the probability of martensite formation is lower, which should cause the IF peak temperature displacement (from 160 to 140 K Figs. 1, 2).

It is know that IF peak, generated by phase transformations, is accompanied by Young's modulus E anomalies at transition temperature T_f [3, 6, 9]. As the measurements show, there is a change curve of $E(T)$ curve for monophase samples (100 % β) in the T_m range (Fig. 1). This confirms the existing of $\beta\leftrightarrow\alpha$ phase transformation.

At the same time, the absence of obvious modulus change for two-phase alloy as well as much smaller width and height of the peak (Fig. 2) can indicate the decrease of T_f lower than even nitric temperatures. In this case, the dependence $\delta(T)$ at 140 K is influenced only by relaxation IF maximum component.

Nonuniform and nonstationary internal thermal stresses, which appear during the quenching, also give some contribution to wide IF maximum forming. They make for α'' martensite forming and much influence the energy conditions around the impurities, changing the relaxation conditions.

Stress misfits also affect IF peak, appearing on the phase boundaries due to damping capacity anisotropy and thermal expansion of various phases. These stresses can have rather big value ($\sigma_{mf} \approx 50$ MPa at cooling for 200 K), according to evaluations produced in [10].

As the studies show, damping logarithmic decrement absolute value β correlates with the structural state of the alloy. When monophase alloy is deformed by stretching, the observed structure (of dislocations, martensite layers) defects increase [8] is accompanied by damping δ_{300} increase. In case of more complicated deformation pattern during hydroextrusion, the defects increase causes the increase of IF (Fig. 3). The increase of quenching defects with higher quenching temperature (Fig. 4) is also accompanied by damping decrement δ_{300} increase. The experiment showed a serious effect of quenching temperature on the modulus of elasticity. If the modulus value in two-phase alloy can be caused by the strengthening influence of two-phase boundaries and β-phase enrichment in dopants, then the coefficient increase at temperatures higher than 900°C may be connected with the increase of hydrogen absorption [2]. The most interesting result is the sufficient decrease of Young's modulus after quenching from 900°C, i.e. in monophase β-alloy. We have found a region of low-modulus state, in which alloy deformation is much easier, in the alloy. A similar decrease of the modulus was observed in other titan alloys: Ti–12Ta–9Nb–6Zr and Ti–23Nb–33Zr [11]. The state of the material with the low modulus is named "rubber"-state. The decrease of the modulus testifies to the change of atom interaction character, the latter can be caused by the change of β-phase solid solution composition.

So, we can conclude that the research of IF temperature dependencies on the modulus of elasticity in Ti–5Al–5Mo–5V alloy discovered the peaks in 140–160 K temperatures range. The maxima parameters depend on the phase state and thermomechanic stresses. The IF effects observed are caused by the processes of low-temperature martensite $\alpha'' \leftrightarrow \beta$ transformation and point defects relaxation in the field of changing internal stresses. A low-modulus state, at which the deformation conditions are facilitated, is found out to form in the alloy after quenching at temperatures about 900°C (100 % β-phase).

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Вплив фазового складу на непружні властивості сплаву Ti–5Al–5Mo–5V

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Вивчено вплив фазового складу сплаву Ti–5Al–5Mo–5V на температурні залежності внутрішнього тертя та модуля Юнга у діапазоні 78–300 К. Фазовий склад сплаву регулювався зміною температури нагрівання під загартовування. Установлено існування максимуму внутрішнього тертя при 140–160 К, параметри якого залежать від фазового складу сплаву. Проведено аналіз процесів, які відповідають за формування піку. Виявлено значне зниження модуля в однофазному β-сплаві після гартування від 900°С.