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HEAT TREATMENT OF THE VT22 ALLOY

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Foreign Technology Division
Wright-Patterson Air Force Base, Ohio

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В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

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RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

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rot	curl
lg	log

GREEK ALPHABET

Alpha	Α	α	α		Nu	Ν	ν	
Beta	Β	β			Xi	Ξ	ξ	
Gamma	Γ	γ			Omicron	Ο	ο	
Delta	Δ	δ			Pi	Π	π	
Epsilon	Ε	ε	ε		Rho	Ρ	ρ	ϱ
Zeta	Ζ	ζ			Sigma	Σ	σ	ς
Eta	Η	η			Tau	Τ	τ	
Theta	Θ	θ	ϑ		Upsilon	Τ	υ	
Iota	Ι	ι			Phi	Φ	φ	ϕ
Kappa	Κ	ϰ	κ	ϰ	Chi	Χ	χ	
Lambda	Λ	λ			Psi	Ψ	ψ	
Mu	Μ	μ			Omega	Ω	ω	

HEAT TREATMENT OF THE VT22 ALLOY

O. V. Kasparova, A. A. Gelbman, I. S. Polkin,
N. I. Kolodkin, and L. S. Kornilova

We examined the basic laws governing a change of the phase composition structure and properties of semi-finished products made from the VT22 alloy of industrial composition depending on the mode of heat treatment.

Annealing

An increase in temperature and an increase in the duration of heating in the ($\alpha+\beta$) region is accompanied by a coarsening of the intragranular structure, a monotonic increase in the beta-phase number and the dimensions of α-plates. The VT22 alloy, to a greater degree, than the VT3-1 and VT8 alloys, is sensitive to the rate of cooling. The effect of cooling rate is manifested at the heating temperatures in the ($\alpha+\beta$) region of over 700°C. With a decrease in the mean rate of cooling[1] - from 85 degrees per minute (air) to 0.3 degrees per minute (furnace) - there is a more complete isolation of particles of the secondary α-phase from the β-solution (Fig. 1), which leads to the formation of an interlaced framework

[1]The mean rate of cooling is shown for the interval "heating temperature - 350°C."

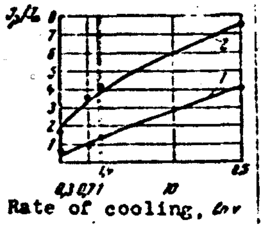

Figure 1. The ratio of intensity of β- and of α-phase lines as a function of the cooling rate: 1 - J_β (110), J_α (0002); 2 - J_β (110), J_α (1010).

consisting of α-plates (Fig. 2).

Figure 2. Microstructure of the VT22 alloy after the heat treatment under different conditions: a) 780°C, 1 h ($v_{охл.}$=85 deg/min); b) 780°C, 1 h ($v_{охл.}$=1.4 deg/min); c) 780°C, 1 h, ($v_{охл.}$=0.3 deg/min); d) 900°C, 1 h, water + 350°C, 5 h, air; e) 900°C, 1 h, water + + 600°C, 5 h, air (a, b, c - ×14000; d, e - ×20000).

As a result there is an increase in strength, a decrease in plasticity and resistance to impact bending (Fig. 3). A change in the mechanical properties is especially noticeable in the range of small rates of cooling (0.3-1.5 deg/min).

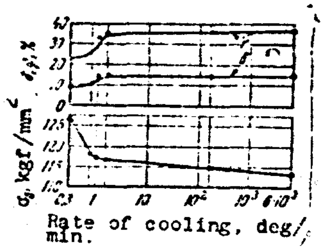

Figure 3. Mechanical properties of the VT22 alloy as a function of the cooling rate from the (α+β)-region.

The structure nature and the phase composition of the alloy during the heating in the β-region are determined completely by the rate of subsequent cooling. During cooling from the β-region in the air there is a partial decomposition of the β-solution with the formation of the ω-phase. During cooling with the furnace (<5 deg/min) a (α+β) Widmanstatten-type structure is formed. The decomposition of the β-solution with the formation of the ω-phase causes a sharp embrittlement of the alloy, not observed at other rates of cooling.

An optimum combination of strength and plasticity in the VT22 alloy (σ_b=110-120 kgf/mm^2; δ=10-15%; ψ=35-50%; a_H=2.5-3.5 kgfm/cm^2) is obtained during the heating in the (α+β)-region to 700-800°C with a subsequent cooling in the furnace. Isothermal holding (up to 2 h) at 450-600°C during the cooling of the alloy with the furnace from 700-800°C virtually has no effect on the mechanical properties.

An isothermal holding for 2 h with stepped annealing in the (α+β)-region (700-800°C) has considerable effect on the structure and properties. By stepped annealing we mean a heat treatment which involves a transfer to another furnace, from the temperature of heating to the temperature of isothermal holding. A temperature decrease in isothermal holding from 650 to 450°C is accompanied by an increase in the dispersity of the α-particles, which causes an increase in the strength and a decrease in plasticity. The VT22 alloy, after stepped annealing from a second stage at 450°C, is stronger than after a similar heat treatment with cooling in the furnace (Table).

With identical heating temperatures the strengthening effect during isothermal holding (450°C), due to the precipitation hardening, is higher than during the decomposition of the β-phase in the case of furnace cooling. The nature of the structure and phase transformations with double annealing is similar to that observed during tempering and aging.

Table. The properties of the VT22 alloy annealed at different modes.

Annealing mode	Mechanical properties			
	σ_b, kgf/mm^2	δ,%	ψ,%	a_H kgf/cm^2
780°C, 1 h, cooling with the furnace to 400°C, then in the air............	112	12	30	2.8
780°C, 1 h, transfer to 450°C, 2 h, cooling in the air.	117	10	27	1.9

Strengthening Heat Treatment

Phase composition and the structure of the VT22 alloy in a thermally reinforced state depends on the temperature and the rate of quenched cooling, and also on the aging conditions.

With an increase in the cooling rate from 85 deg/min (air) to 100 deg/sec (water), after heating in (α+β)-region, no significant changes were noted in the structure and in the properties of the alloy (see Fig. 3). Quenching from the β-region in water leads to the fixation of the β-phase with unitary thin-plate separations along the grain boundaries, revealed during the electron-microscope analysis, and, as a rule, eliminates the embrittlement inherent in the air cooling.

Aging at 400-650°C, after cooling in the water and air from the (α+β)-region at temperatures 100-150°C lower than the temperature of (α+β)→ β-transformation leads to a highly dispersed separation of a secondary α-phase from the β-solution. With a decrease in the temperature and rate of quenched cooling, an increase in duration and an increase in the aging temperature, the separations of the secondary α-phase become less dispersed. This is accompanied by a decrease in strength and an increase in plasticity. After cooling from the (α+β)-region from 700-750°C in the water and air, the decomposition of the β-solution, independently of the aging temperature (400-650°C) occurs according to the system $\beta \to (\beta+\alpha)$.

According to the roentgen phase-shift analysis the decomposition nature of the β-phase during aging, after quenching from the β-region in the water and air, is determined by the temperature and time of aging: to 350°C the decomposition occurs according to the scheme $\beta \to (\beta+\omega)$, at 350-400°C – $\beta \to (\beta+\omega) \to (\beta+\omega+\alpha) \to (\beta+\alpha)$, and above 400°C – $\beta \to (\beta+\alpha)$.

The isolation of the ω-phase in the VT22 alloy during aging is accompanied by the appearance of a surface relief in grains of the β-phase (Fig. 2d). A similar relief was observed by the authors of work [1] with the formation of the ω-phase in the Ti alloy – 16% of V – 2.5% of Al.

The specific resistance of the VT22 alloy, after quenching from the β-region in water and aging at 350-600°C, is decreased in comparison with the hardened state. The decrease in electrical resistance is more significant in the region β→α-transformation (up to ~15%) and is less noticeable in the region β→ω-transformation (up to ~2%). Qualitatively, similar regularities in the change of the specific electric resistance depending on the phase composition were obtained for the Ti alloy – 6.5% of Mn [2].

The strengthening heat treatment which includes quenching from the β-region in water and a subsequent aging is inapplicable for the VT22 alloy due to strong embrittlement (Fig. 4), the formation of the ω-phase (300-400°C) and the separation of a large amount of the highly dispersed α-phase (450-650°C, see Figs. 2d, e).

A dilatometric analysis carried out on the specimens made from the VT22 alloy, with isothermal holdings in the range of 250-400°C

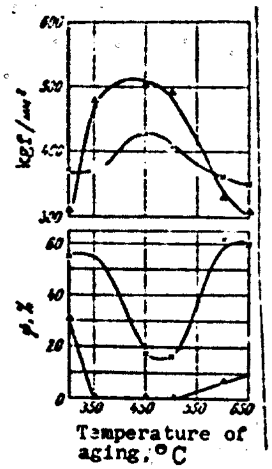

Figure 4. Mechanical properties of the VT22 alloy as a function of the aging temperature (τ=5 h) after the water quenching from 750 (x) and 900°C (▲).

after water quenching from the β-region, showed the presence of contraction effects. A maximum reduction in the length of specimens is acheived at 300°C and ~$15 \cdot 10^{-2}$%. According to the results of the x-ray phase-shift analysis, the contraction of specimens at 250-400°C should be connect with the β→ω-transformation.

Thus, the β→ω-transformation in the VT22 alloy is characterized by the presence of contraction effects, appearance of a surface relief in grains of the β-phase and a slight decrease in the specific resistance.

The special feature of the microstructure of the VT22 alloy, both in the annealed and in thermally reinforced states, is the high dispersity of the α-phase plates, which impedes the study of the structure under a light microscope.

Conclusions

1. High sensitivity of properties of the VT22 alloy to the heat-treatment conditions dictates a need for a stricter regulation of the heat-treatment parameters (heating temperature, rate of cooling and holding time) than for the medium-alloyed (α+β)-alloys.

2. An increase of the annealing temperature in the (α+β)-region

and an increase in the rate of subsequent cooling from 0.3 to 85 deg/min is accompanied by a decrease in the strength indices and an increase in the characteristics of plasticity. Depending on the type of a semi-finished product and the inertness of thermal equipment, an optimum annealing temperature is selected in the range of 700-800°C.

3. The best complex of mechanical properties in the thermally reinforced state is achieved in the VT22 alloy after cooling from 700-750°C in water and subsequent aging at 500-550°C for 5-10 h (σ_b=130-140 kgf/mm^2; δ=7-10%; ψ=20-30%).

The same level of properties can be obtained by double annealing with a lower temperature in the second stage. This simplifies the technology of the strengthening heat treatment.

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