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Formability and resistance to deformation of selected titanium alloys

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Exploitation of beneficial plastic properties of Ti_{β} structural phase is significantly limited at hot forming. Due to this, but also due to structural and mechanical properties, use of titanium alloys is prevalent.

There are used particularly alloys with occurrence of (α+β) zone, which makes it possible to obtain very good resulting structures with high yield value and good plastic properties. Representative of the type of two-phase alloys at hot deformation is TI6Al4V alloy, for which we investigated its resistance to deformation and formability.

1. INTRODUCTION

Manufacturing of formed structural elements made of titanium alloys is performed particularly by hammer forging and die forging, extrusion and rolling. Titanium (and also titanium alloys) are characterised se by temperature of allotropic change in the interval of approx. 880 to 888 ^{o}C. At temperatures around 885 ^{o}C titanium has hexagonal structure (α phase); at temperatures exceeding 888 ^{o}C the α phase is transformed to β phase [1], which has cubic stereocentric lattice. Influence of chemical composition on temperatures of polymorphous transformation are for the alloy TiAl6V4 illustrated in Fig. 1. Structures with hexagonal lattice have at lower temperatures smaller number of slip planes and thus also lower plastic properties, which causes difficulties at cold forming. Number of slip planes in hexagonal lattice increases with increasing temperature and plastic properties also improve. Titanium alloys have substantially higher plastic properties at the interval of temperatures of β phase.

Titanium alloys are for these reasons characterised by limited formability at low temperatures, and by considerably higher formability at high temperatures [2]. Forming of titanium alloys is therefore most frequently realised as hot forming in temperature interval from 900 ^{o}C to 1100 ^{o}C. Two-phase zone α+β, which in many alloys is comparatively narrow, can be extended by addition of other elements. For example for the alloy Ti5Al2,5Sn the zone α+β is in the interval of temperatures from 980 to 1040°C.

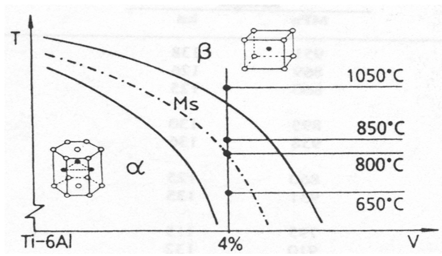

Fig. 1 Influence of chemical composition on temperature of polymorphous change

Addition of approx. 0,3 % Fe extends this zone by more than 100°C. Only at flat forming, e.g. drawing of sheets, this is performed at temperatures of approx. 500 to 600 °C. Cold forming of titanium alloys can be used in case of comparatively small deformations.

2. MATERIALS AND EXPERIMENTAL METHODOLOGY

Experimental verification of deformation behaviour of titanium and its alloys has been performed with use of technically clean titanium and alloy of the type α and alloy (α+β), which have the largest use in industry: Ti 99,5; alloys TiAl6V4, TiAl5Sn2,5. Chemical composition of verified alloys is given in the Tab. 1

Table 1. Chemical composition of titanium and titanium alloys

Alloy	Chemical composition [mass %]									
	Al	Sn	V	N	C	H	Fe	O	other	Ti
Ti 99,0*				Max. 0,05	Max. 0,10	Max. 0,015	Max. 0,50	Max. 0,40		rest
Ti 99,0**				0,03	0,08	0,015	0,14	0,15		
TiAl6V4*	5,5-6,75		3,5-4,5	Max. 0,05	Max. 0,08	Max. 0,01	Max. 0,3	Max. 0,2	Max. 0,4	rest
TiAl6V4**	5,4		4,1	0,03	<0,08	<0,015	0,14	<0,15	0,05	rest
TiAl5Sn2,5*	4,0-6,0	2,0-3,0		Max. 0,05	Max. 0,10	Max. 0,02	Max. 0,4	Max. 0,2	Max. 0,4	rest
TiAl5Sn2,5**	5,4	2,3	0,03	0,02	0,02	<0,015	0,08	<0,15	0,4	rest
Note: * values given in ASTM B265 ** measured values										

We have investigated impact of testing temperature in the temperature interval (320), 700 to 1200 °C on formability and resistance to deformation, at deformation rate 10^{1} to 10^{-2} s^{-1}, at magnitude of relative deformation ε = 5 to 80 % [3]. Values of resistance to deformation are given in the Tab. 2.

The tests were made with use of mechanical upsetting of rolled samples. For upsetting test there were used the samples with dimensions: d_o = 13 mm and h_o = 15 mm. Contact surfaces on sample fronts were modified for application of lubricant. Lubrication of samples' fronts was effected by lubricants currently used for forming of titanium.

The samples were re-heated in laboratory electric furnace in protective argon atmosphere. At least three samples have been verified for each temperature.

Deformation forces were measured by strain gauge, change of sample height was measured by electromagnetic sensor. The obtained values were computer processed with use of the program DAS16. Graphical representation of dependence of formability and resistance to deformation on temperature is for the alloy TiAl6V4 shown in Figures 2 and 3.

Table 2. Resistance of titanium and its alloys to deformation

Grade	Structure	Temperature			
		900 °C		800 °C	
		$\dot{\varepsilon}=10^{1}\ s^{-1}$	$\dot{\varepsilon}=1\cdot10^{-2}\ s^{-1}$	$\dot{\varepsilon}=10^{1}\ s^{-1}$	$\dot{\varepsilon}=1\cdot10^{-2}\ s^{-1}$
		σ_d $[MPa]$	σ_d $[MPa]$	σ_d $[MPa]$	σ_d $[MPa]$
Ti	α	50	29	96	54
T6Al4V	ααβ	171	87	396	205
Ti5A12,5Sn	ααβ	200	141	500	300
Ti6A15ZrMo	ααβ	425	28	> 700	08
Til0V2Fe3Al	β	143	36	228	64
Ti15V3Cr3A13Sn	β	242	71	321	121

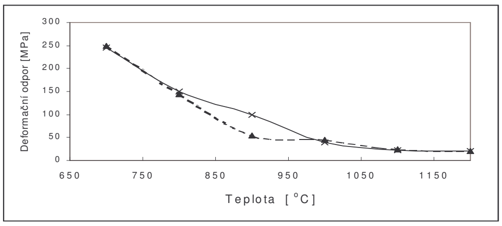

Fig. 2 Example of dependence of resistance to deformation on deformation temperature for the alloy TiAl6V4 :
(- - - as cast; ___ as formed)

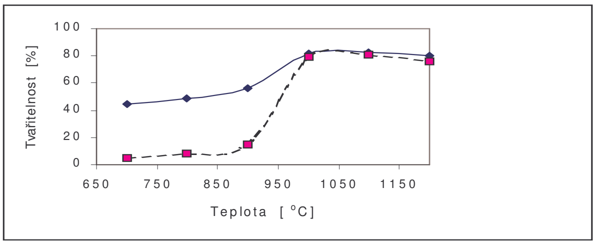

Fig. 3 Examaple of dependence of formability on deformation temperature for the alloy TiAl6V4 :
(- - - as cast; ___ as formed)

3. RESULTS AND DISCUSSION

It was proved by processing and analysing the obtained values that mean square error of testing inn individual points varies around 8 to 11 % with correlation coefficient 0.95. Figure 2 shows curves of temperature dependence $\sigma - t_{zk}$ of the alloy TiAl6V4 in the temperature interval from 700 to 1200 ^{o}C. At the specified rate of deformation there occurs a significant softening of titanium alloys, which is related to achievement of re-crystallisation temperature and polymorphous transformation. Figure 3 illustrates dependence of ε - t_{zk} for the same alloy.

The following dependencies were chosen for approximation of curves obtained at tests:

a) at coordinates $\varepsilon - t_{zk}$

$$\varepsilon = \gamma \cdot t_{zk}^{\beta} \tag{1}$$

where γ and β are function of temperature t_{zk}

b) at coordinates σ - t_{zk}

$$\sigma = k \cdot T_{zk}^{\lambda} \cdot e^{n} \tag{2}$$

where k, λ, n are constants

Example of coefficient of equation (2) of dependence of σ on t_{zk} are given in the Table 3.

Table 3. Coefficients of dependence of σ on deformation temperature

Alloy	Coefficients in temperature interval, °C					
	320 to 700			700 to 1200		
	k	λ	n	k	λ	n
TiAl6V4*	128,9	0,038	-1,42	$4x10^{-9}$	-25,5	21,53
TiAl6V4**	97,76	-0,02	-1,42	$7{,}2x10^{-3}$	-11,89	7,2
TiAl5Sn2,5	140,2	0,05	1,64	$2{,}3x10^{-6}$	-19,63	15,5
Ti99	149,3	0,055	1,33	$9x10^{-8}$	18,46	-23,88
Condition: as formed,** as cast*						

At deformation there occur changes of structure. Originally cast structure gets in dependence on magnitude of deformation significantly refined.

Transformation of original cast structure of the alloy TiAl6V4 (Fig. 4) in dependence on deformation (Fig. 5) and on thermal treatment after forming is shown in Fig. 6.

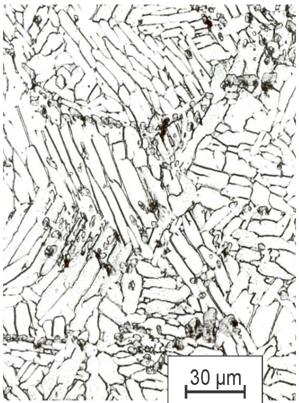

Fig. 4. Microstructure of TiAl6V4 in cast condition

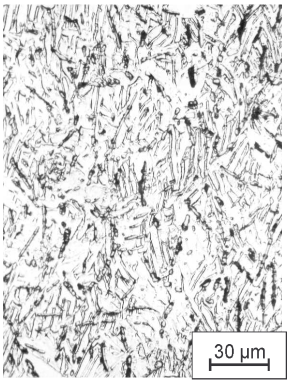

Fig. 5. Microstructure of TiAl6V4 after hot forming

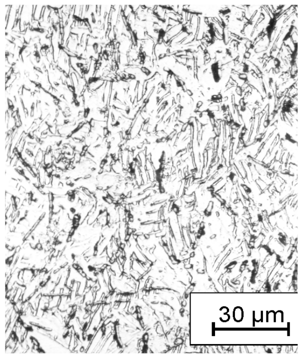

Fig. 6. Microstructure of TiAl6V4 after hot forming and annealing at temperature of 680 ^oC

4. CONCLUSION

Basic factors influencing formability and resistance to deformation of titanium and its alloys are the following:
chemical composition, microstructure and macrostructure, deformation temperature, rate of deformation and state of stress. At deformation with full re-crystallisation resistance to deformation remains at rates of deformation $\varepsilon' < 10^1 s^{-1}$ almost constant. Change of resistance to deformation at hot forming can be caused by change of temperature, significant change of deformation rate, or possibly by polytropic transformations. At forming below re-crystallisation temperatures resistance to deformation increases due to influence of deformation strengthening, and it therefore significantly depends on magnitude of deformation. At annealing of the formed alloy TiAl6V4 at temperatures around 700 ^oC there occurs re-crystallisation, the course of which depends also on magnitude of preceding deformation. At annealing of this alloy at temperatures around 880 ^oC there occurs substantial coarsening of grain. At temperatures of annealing around 990 ^oC the coarsening of grain is very intensive. Our investigation has confirmed the principle that it is appropriate to anneal the alloys of the type Ti6AlV4 at temperatures below 1000 ^oC [4].

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