

# THE INFLUENCE OF THE SURFACE ROUGHNESS OF SHEET BILLETS OF TITANIUM ALLOY VT6 ON QUALITY OF THE SOLID STATE JOINING UNDER LOW TEMPERATURE SUPERPLASTICITY CONDITIONS

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**Abstract.** The influence of the surface roughness of the sheet billets on quality of the solid state joining under low temperature superplasticity conditions was investigated. The obtained results show that the smallest relative long range area of pores in the zone of joining achieved after polishing of the joined surfaces. The largest pores extension is observed after cleaning by a metallic brush. Vacuum annealing of the solid state joined samples out of titanium alloy VT6 at temperature 750 °C does not eliminate porosity and negative influence on mechanical properties.

## 1. INTRODUCTION

The terms of the solid state joining are conditioned by the surface state of the joining sheets including surface microgeometry processed from superplastic deformation prior to the solid state joining (SSJ). The data on increasing surface roughness in samples with microcrystalline structure (MC) during superplastic deformation are given in [1] and it is assumed that roughness exerts a negative effect on mechanical properties of SSJ.

However at the moment of work performance the results about the influence of roughness of surface on weldability of nanocrystalline materials were absent. Therefore the carrying out of the direct experiment on the influence of the roughness of surface on the quality of SSJ under low temperature superplasticity conditions was considered to be interesting.

## 2. MATERIAL AND METHOD OF TESTING

Industrial two-phase titanium alloy VT6 with standard chemical composition (GOST 19807-91) was used for investigations. The initial sheets billets had MC structure with a mean grain size of 3-5  $\mu\text{m}$  (Fig. 1a). After multi-step forging of initial sheets a nanocrystalline structure (NC) with a mean grain size – 0.2  $\mu\text{m}$  [2] was processed (Fig. 1b).

A special operation i.e. quality reproduction of joint surfaces is used under the pressure welding. Roughness data after the preparation of the surface of VT6 alloy in two conditions – MC and NC by different methods: mechanical diamond paste polishing, zero grain grinding, acid etching and cleaning by a hog is given in Table 1.

The surface roughness was checked by profilograph – profilometer of ME-10 type on 5 basic lengths.

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**Table 1.** Surface roughness ( $R_a$ ) of VT6 titanium sheet after different types of treatment.

$R_a$ , $\mu\text{m}$	Treatment type			
	polishing	grinding	etching	hog
MC	0.06	0.08	0.26	0.53
NC	0.04	0.06	0.15	0.43

**Table 2.** Mechanical Properties of Alloy VT6 at 20 °C.

State of the alloy	$\sigma_r$ , MPa	$\sigma_{0.2}$ , MPa	$\delta$ , %
MC	1126	1024	12
NC	1320	1250	7,5

The minimal roughness of the surface is observed after mechanical polishing of the surface and the maximum is observed after cleaning with a wire brush, as we can see it the table.

The mechanical properties of alloy VT6 at room temperature are presented in Table 2. It can be seen that the NC states are ensured in alloy VT6 by the unique combination of elevated strength and ductility without additional heat treatment.

The joining of the sheet billets with the different structural states, assembled in a package, was performed in a dies block, that included force plates and fixing elements [3]. The assembly was tied up with the strength elements of dies and then placed into the vacuum furnace.

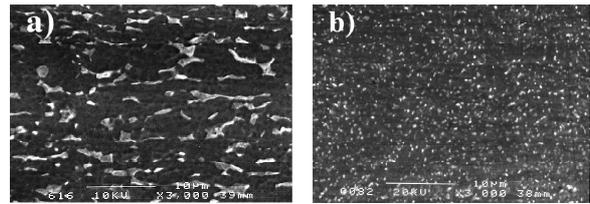
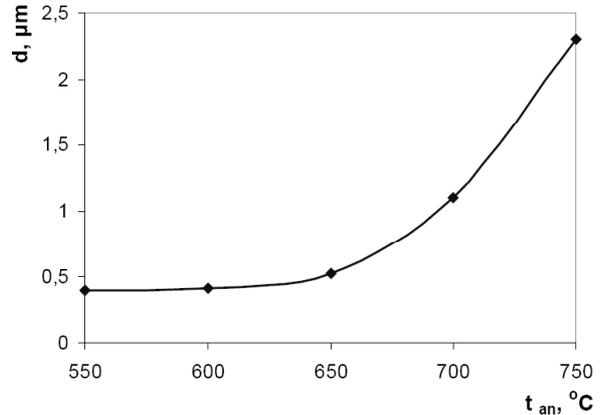
Solid state welding was performed at 750 °C in low temperature superplasticity held during 120 min by applying gaseous argon (pressure 2 MPa) from the pipe connection via flexible membrane on to the welded samples. The vacuum depth in the process of the test was not less than  $2.0 \times 10^{-3}$  Pa.

Metallographic examinations were carried out using an optical microscope Nikon L150 and a JXA-6400 scanning electron microscope.

The quality of SSJ was evaluated by mechanical tensile tests by methods which explained detailed in [4] and metallographically [5] regarding relative long range areas of pores in the zone of joining

$$L_p = \frac{L_{pi}}{L_o},$$

where  $L_{pi}$  - is the total length of micropores along the joint line,  $L_o$  - is the gauge length of the investigated joining along the joint line in the plane of the section.

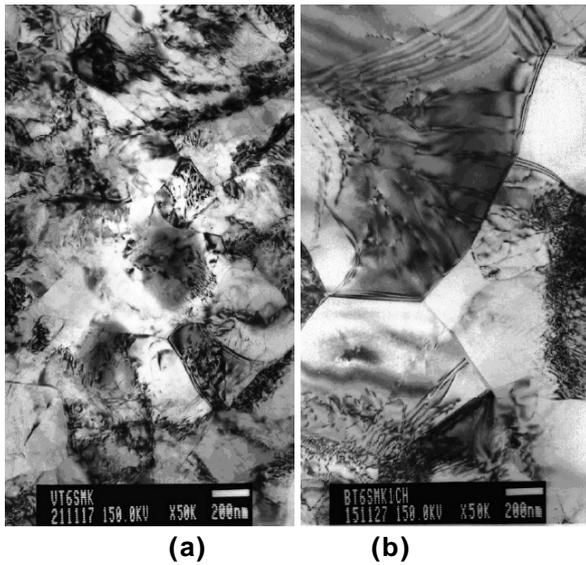
**Fig. 1.** VT6 alloy microstructure in initial states: a) MC; b) NC.**Fig. 2.** Effect of the temperature of vacuum annealing ( $t_{an}=1$  h) on the grain size of NC alloy VT6.

Mechanical characteristics of investigated welded joint was evaluated by the tensile test at the room temperature on "INSTRON 1185" machine.

### 3. RESULTS AND REVISION OF THEM

The phenomenon of accelerated grain growth in titanium alloys subjected to superplastic deformation as compared with simple annealing at the temperature of manifestation of superplasticity is well known [6,7]. The curve of grain growth in titanium alloy VT6 in the temperature range of manifestation of the effect of low-temperature superplasticity is presented in Fig. 2.

The main problem arising in the treatment of these promising materials, in pressure welding in the state of superplasticity in particular, is connected with the instability of the initial structural state. This circumstance limits substantially the temperature and time parameters of the treatment, which should minimize the grain growth and the degradation of the NC state. The intensive grain size growth is observed under vacuum annealing at 650 °C during 60 min. Nanocrystalline alloy transfers to microcrystalline state after annealing at 750 °C. Temperature increasing of vacuum annealing till 750 °C promotes to intensive reduction of strength NC alloy (Fig. 3a) in compare with industrial MC alloy VT6 (Fig. 3b) [8].



**Fig. 3.** Microstructure of titanium alloy VT6. Transmission electron microscopy of a thin foil: a) initial state ( $d_g = 0.2 \mu\text{m}$ ); b) after Vacuum Annealing at  $750 \text{ }^\circ\text{C}$  ( $t_{\text{an}} = 1 \text{ h}$ ).

It has been shown experimentally that when bonding nanostructured sheets of the titanium alloy VT6 under a normal pressure corresponding to the superplastic flow stress, the welding temperature may be essentially lowered [9]. Of a great practical interest is the possibility of bonding nanostructured sheet semi-products at reduced temperatures (in the range  $T = 650\text{--}750 \text{ }^\circ\text{C}$ ) not only with each other, but also to industrial sheet semiproducts with the grain size  $d = 5\text{--}8 \mu\text{m}$  [10,11].

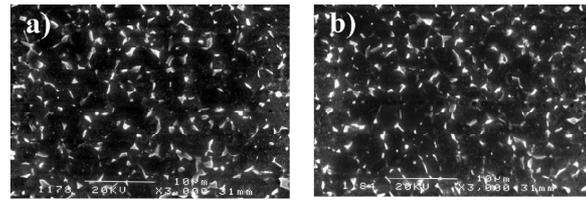
To study the influence of the surface roughness of VT6 titanium alloy sheets billets on the quality of

**Table 3.** Roughness influence on pore ( $L_p$ ) characteristics within the SSJ zone after pressure welding at  $750 \text{ }^\circ\text{C}$ .

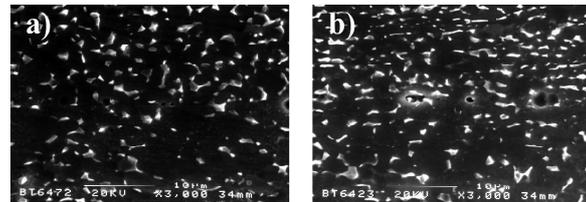
$L_p, \%$	Treatment type			
	polishing	grinding	etching	hog
MC	16	18	42	46
NC	6	16	26	32

**Table 4.** Influence of surface roughness on size of micropores ( $S_p$ ) in SSJ zone after pressure welding at  $750 \text{ }^\circ\text{C}$ .

$S_p, \text{mm}$	Treatment type			
	polishing	grinding	etching	hog
MC	3.2	5.5	7.6	10
NC	1.4	2.1	3.5	5.3



**Fig. 4.** – SSJ construction zone, made of VT6 titanium alloy with NC structures: a) after abrasive polishing and b) after cleaning with the wire brush.



**Fig. 5.** SSJ construction zone, made of VT6 titanium alloy with NC and MC structures: a) after abrasive polishing and b) after cleaning with the wire brush.

the solid state joining, two type constructions have been produced: the first one consisted of sheets with NC-structures and the second one with MC-structures.

Zone of solid state joining constructions of titanium alloy VT6 with NC-structures after abrasive polishing (a) and cleaning with a wire brush (b) is demonstrated in Fig. 4.

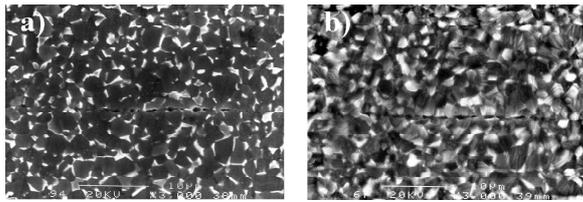
Zone of solid-phase joining constructions out of titanium alloy VT6 with NC-structures and MC-structures after abrasive polishing (a) and cleaning with a wire brush (b) is demonstrated in Fig. 5.

Metallographic analysis of the zone of solid-joining construction out of titanium alloy VT6 with NC-structures and MC-structures after abrasive polishing and cleaning with a wire brush allow to find patterns of microstructural changes.

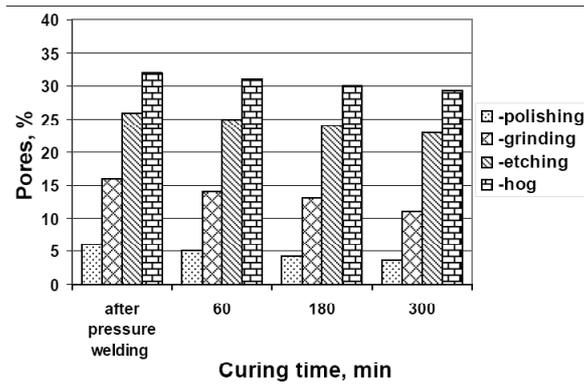
The data on influence of the surface roughness of titanium alloy VT6 on the length and the average area of pores in SSJ zone in two states (MC and NC) after pressure welding at  $750 \text{ }^\circ\text{C}$  are demonstrated in Tables 3 and 4.

The minimum relative volume fraction of pores in joining place can be reached after polishing of the coupled surfaces, and the maximum relative volume fraction (of length) in joining place can be reached after cleaning with the wire brush. When using the NC-structures for pressure welding, there is a significant reduce of surface roughness as compared to MC-structures.

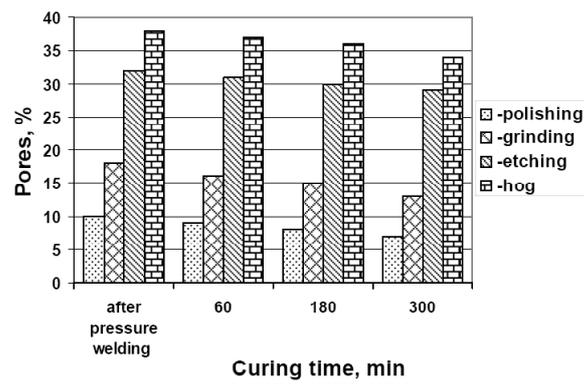
Conversion of the titanium alloy VT6 into nanostructural state leads to reducing of the aver-



**Fig. 6.** SSJ construction zone, made of VT6 titanium alloy with NC structures: a) after pressure welding and b) the same area after vacuum annealing during 300 min.



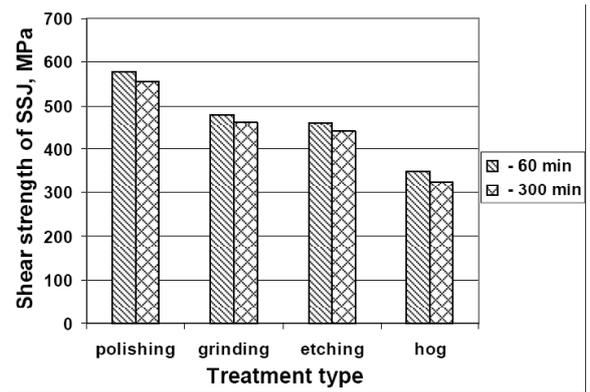
a



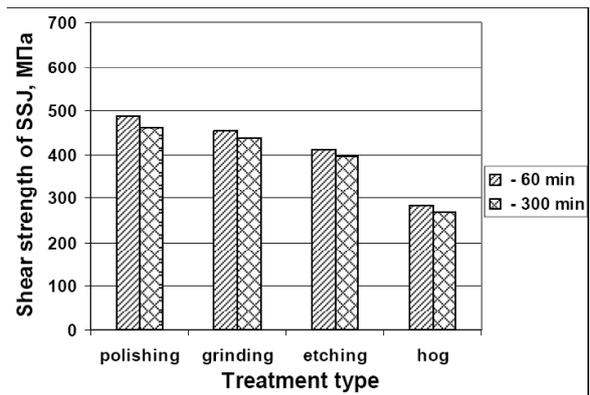
b

**Fig. 7.** Relative volume fraction (of length) of pores in joining place after pressure welding at different states of VT6 titanium alloy surface between: a) NC+NC; b) MC+NC.

age grain size and increase of total length of nonequilibrium boundaries. It is possible due to significant activation of the diffusive processes [12]. Relaxation after unloading leads to balanced state of material and is accompanied with redistribution of the whole internal energy. Meanwhile the diffusive mass transfer takes places, resulting in filling of the empty spaces, that have appeared during deformation, taking into consideration that nonequilibrium grains boundaries may have higher diffusion coefficient than equilibrium ones [13]. That is why for evaluation of the influence of diffusive processes on quality of SSJ, the vacuum annealing of



a



b

**Fig. 8.** Mechanical properties on deformation of welded sheets after going through the vacuum annealing during 60 and 300 min between: a) NC+NC; b) MC+NC.

samples consisting of single pores or chains of pores in SSJ zone, have been held.

The precision test has shown that the vacuum annealing at 750°C during 60 to 300 min does not lead to critical reduce of quantity and size of pores, exception of smallest pores, that are significantly smaller than the grain size in sheets joining zone of VT6 titanium alloy (Figs. 6a and 6b). This principle represent for solid state welding of VT6 alloy with MC-structure and for sheets out of VT6 alloy with NC-structure.

The changes of relative volume fraction (of length) of pores at different time of vacuum annealing of VT6 titanium alloy with different structure states are listed in Figs. 7a and 7b.

The mechanical tests demonstrated, that after vacuum annealing for 60 min, the strength is reduced (Figs. 8a and 8b). After vacuum annealing for 300 min, the strength of welded sheets keep on reducing due to grow of grains size [14], that leads to loss of unique physical and chemical properties of NC VT6 alloy [15].

Therefore, the vacuum annealing at 750 °C has no significant influence on pore reduce, and it does not lead to increase of mechanical strength in solid state joining zone.

#### 4. CONCLUSIONS

The investigations of microstructures of SSJ with different roughness were undertaken. It is established that with decreasing roughness the quality of SSJ improves by decreasing long range areas and sizes of pores in conditions of low temperature superplasticity.

Vacuum annealing at temperature 750 °C and time of 60 to 300 minutes does not lead to remarkable decreasing of amount and size pores in the welding zone and negative influence on mechanical properties of NC VT6 alloy material.

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