FEATURES OF FORMATION OF CRYSTALLOGRAPHIC TEXTURE AND PROPERTIES IN Ti-3Al-2.5V TITANIUM ALLOY DURING TUBES MANUFACTURE

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Texture formation processes at all technological stages of tube manufacture were considered. It has been established that at the stage of hot deformation and manufacture of TREX tubes, tangential and radial textures are formed, a large share of tangential component of the texture. Influence of main factors of the technological process on formation of texture and properties was established. Conditions for formation of a maximum amount of radial texture in tubes which ensure improvement of service properties of tubes were determined. To create maximum amount of radial texture in tubes, total reduction rate in passes and the wall to diameter reduction ratio (factor Q) are important. The reduction rate should be increased, especially in the last passes, to 75…85%. Heat treatment (stress relief annealing) practically does not change the tube texture.

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INTRODUCTION

Titanium and its alloys are widely used in nuclear, aviation and aerospace engineering. It is known that titanium is anisotropic material due to its hcp crystal lattice [1]. An increase in the interest paid to the problems of controlling anisotropic properties of materials is observed recently and, therefore, to the problems of texture formation during manufacture of products. Textured materials are developed and produced with a high level of properties in certain directions achieved through the use of crystalline anisotropy. The texture study and prediction make it possible to manufacture products with a prescribed set of properties. As applied to Ti-3Al-2.5V alloy tubes, a new indicator was introduced in technical requirements to tubes – contractive strain ratio (CSR). This is called compression deformation factor (CDF) [2]. This indicator indirectly characterizes the metal texture (by analogy with orientation of hydrides in tubes made of zirconium alloys). Analysis of published data shows that reliability of tubes made of titanium and its alloys is largely determined by requirements to the texture formed in tubes during their processing.

Lower symmetry of the α-Ti hexagonal crystal lattice being the main phase of most industrial Ti alloys combined with features of crystallographic texture of titanium products largely determine anisotropy of physical and mechanical properties and characteristics of corrosion, creep, strength under internal hydrostatic pressure and fatigue strength [1].

In addition, texture anisotropy plays an important role in the problems associated with material processing. Pronounced orientation of basal planes during rolling of metals with hcp crystal lattice suggests actions of an increased roll force during rolling of α-titanium alloys [3].

Primary orientation of basal planes may also inhibit orientation during further processing operations.

In this regard, optimization of the process of manufacturing products from titanium and its alloys requires knowledge of the laws of texture formation in them under various types and modes of plastic working and heat treatment.

One of the most important properties of hydraulic tubes is fatigue resistance. The results of a number of studies [3, 4] have shown that when fatigue tests are performed, tubes with a radial texture are superior to hydraulic tubes with a tangential texture.

Formation of textures of certain types in making titanium tubes is a new challenge for Ukrainian pipe and tube industry requiring serious studies.

Conventional flow diagram of manufacture of titanium tubes includes the following processes: hot extrusion, a series of cold rolling passes with intermediate annealing in vacuum and final heat treatment which can be recrystallization or stress-relief annealing vacuum. Further, tubes are subjected to careful control by various methods.

The stressed state diagram of the metal when rolling tubes differs significantly from that when rolling sheets, wires, etc. Therefore, it should be taken into account both when choosing pressing parameters and when designing schedules and modes of working and heat treatment to obtain mainly radial texture and required set of properties.

THE STUDY OBJECTIVE

The study objective was establishing patterns of formation and transformation of texture and properties at all stages of tube manufacture from Ti-3Al-2.5V titanium alloy and preparing recommendations to ensure required operational properties.

MATERIAL AND TECHNIGUE

The Ti-3Al-2.5V titanium alloy widely used in aircraft engineering was chosen as a study material. Its chemical composition is presented in Table 1.

Table 1

Chemical composition of the Ti-3Al-2.5V alloy

Element content, wt.%						
Al	V	Fe	C	N	O	Ti
2.5-3.5	2.0-3.0	<0.3	<0.05	<0.02	<0.12	main

Studies were performed with specimens prepared from tubes after extrusion, TREX (Tube Rolling Extrusion) tubes as well as tubes after first, second and third passes of cold working and heat treatment.

Crystallographic texture, structure, mechanical properties of tubes were studied and tests for fabrication characteristics (flattening, expansion and bending) were conducted in technological steps of stock processing. Mechanical properties in tension were determined in accordance with GOST 10006-80. Microstructure was assessed using Axiovert-40 MAT optical microscope. Tests for fabrication characteristics were carried out in accordance with requirements of regulatory documents [2].

Crystallographic texture was examined by X-ray diffraction analysis in CuK_α radiation using DRON-4 installation. Full-profile 2θ-angular diagram of intensity of X-ray reflection from the outside tube surface (radial, R) and from the plane of longitudinal section (tangential, T) was recorded. Studies have been performed on composite specimens of riveted tube segments to broaden irradiation area. Specimens were specially prepared: they were ground, polished and then the surface layer was etched off (Fig. 1).

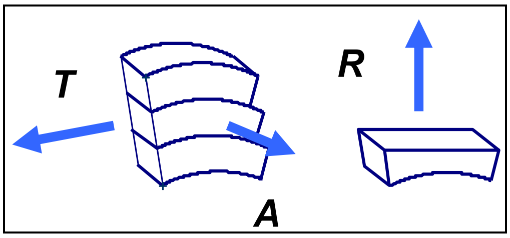


Fig. 1. Illustration of measurement projections

Intensities of the X-ray lines and density of poles were determined for each measurement by the Harris-Morris method [5, 6] and the Kearns texture coefficients (*f*) [7] were calculated as well. The Kearns parameter was calculated by the formula:

$$f = \sum_i A_i P_i \cos^2 \alpha_i \ ,$$

where α_i is the angle between the [00.1] axis of the material crystallites and the normal to the measurement surface. A_i is the statistical weight of corresponding reflections on the spherical projection ($\Sigma A_i = 1$). P_i is the density of poles for each line.

The Kerns parameter can be a certain fractional (percentage) measure of orientation of the crystallographic planes relative to a given surface, that is, it characterizes radial and tangential textures. The sum of such parameters in three main geometric directions (measurement directions) for the specimen is equal to one.

Inverse pole figures (IPFs) were built using corresponding software.

RESULTS AND DISCUSSION

To study the tube metal texture, all prepared specimens were subjected to X-ray measurement in radial (*R*) and tangential (*T*) directions.

The study of texture and properties of the extruded stock has shown that it was textured and had both radial and tangential texture components. Moreover, extrusion parameters (temperature, speed and reduction ratio) affected the structure but retained almost the same ratio of radial and tangential texture components. The summarizing Table 2 shows mechanical properties, contractive strain ratio (CSR), Kearns coefficients characterizing ratio of radial and tangential components of the tube metal texture at all production stages as well as the results of tests for fabrication characteristics (flattening and expansion).

The results of studies of texture and properties of the extruded stock are presented in Table 2 and Fig. 2.

Fig. 2 shows the inverse pole figures and the diagram of corresponding values of the texture parameter for the specimens prepared from extruded ∅85×20mm and ∅86×20 mm stock.

As can be seen from the presented results, both specimens were textured. They had both radial and tangential texture components. A slight difference in the values of radial and tangential components was caused by extrusion modes. More detailed studies of extruded tubes are presented in [8].

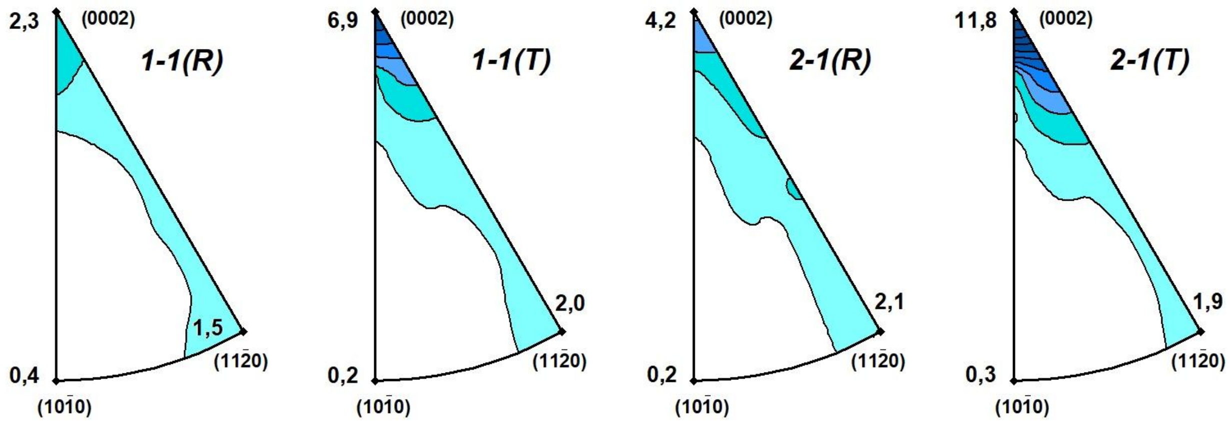
The extruded stock is further subjected to one or two cold working passes to a size of ∅50...38×8...5 mm which is a TREX tube (the stock) for subsequent cold rolling into a smaller size of ∅17...6 mm. Mechanical properties and the Kearns coefficients of TREX tubes of ∅50...38 mm size are presented in Table 2.

Also, examination of texture of the TREX tubes (the stock of ∅50…38×8…5 mm tube size was performed. Inverse pole figures and diagrams of corresponding values of the Kearns texture parameter of the TREX tubes are shown in Fig. 3.

After working and subsequent heat treatment, share of the tangential texture in TREX tubes slightly decreased and share of the radial texture slightly increased. As can be seen from the presented study results, the Kearns coefficients for both TREX tubes were quite close: f_R = 0.46…0.48 and f_T = 0.39…0.44.

Mechanical properties were also reduced since recrystallization was more complete under heat treatment.

Radial texture was sharper after heat treatment in vacuum. Thus, 30…50% reduction of the extruded billet and subsequent heat treatment did not lead to a change in texture of the extruded tubes, but on the contrary, it slightly reduced the texture degree in the material.



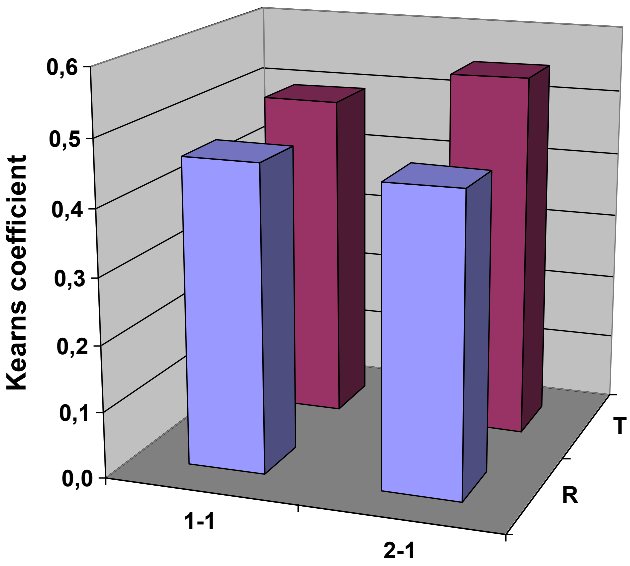


Fig. 2. IPFs of the specimens prepared from extruded stock (pictures at the top) and a diagram of the corresponding texture parameter values (R for radial direction, T for tangential direction)

This was probably caused by incorrectly chosen deformation mode, namely, the reduction rate and its distribution in the wall and diameter.

Thus, the TREX tubes had both radial and tangential textures. All four specimens prepared from the TREX tubes had approximately the same texture. Cold rolling at a low reduction rate did not change presence of the texture formed during extrusion. This is confirmed by the fact that texture in tube of titanium alloy is mainly formed at the stage of hot working by extrusion which is consistent with opinion of the authors of [9].

The study of TREX tubes after heat treatment in vacuum has shown that the obtained structure was a polyhedral, finely dispersed structure of α-titanium with grain size of order of 9…12 μm. There were individual grains of the order of 20 μm (Fig. 4).

The TREX tubes are further cold rerolled in several cold passes to the finial size.

Texture, structure and properties of tubes taken from three stacks were studied in intermediate sizes: ∅25×3.2 mm and ∅17.5×1.7 mm. Integral intensities of X-ray lines were determined, pole densities and the Kearns parameters for ∅25×3.2 mm tubes were calculated (see Table 2).

As can be seen from the table, the Kearns parameters show that share of the tangential texture component increased to f_t =0.49…0.50 after the first rolling pass. However, the texture did not change significantly. Further working by rolling schedule ∅25x3.2 mm → ∅17.5x1.7 mm in the cold worked state has resulted in an insignificant increase in the radial texture component, up to f_r = 0.43…0.44, however, the share of the tangential component was still high: f_t = 0.44…0.51. If we compare radial texture of 43…44% and tangential texture of f_t = 0.45…0.51 obtained after working the ∅17.5×1.7 mm size tubes and radial texture of f_r = 0.45…0.49 and tangential texture of: f_t = 0.44…0.45 obtained after heat treatment, the result is almost the same: just the radial texture component was slightly increased and the tangential one decreased. The results suggest that heat treatment does not fundamentally change the rolling texture.

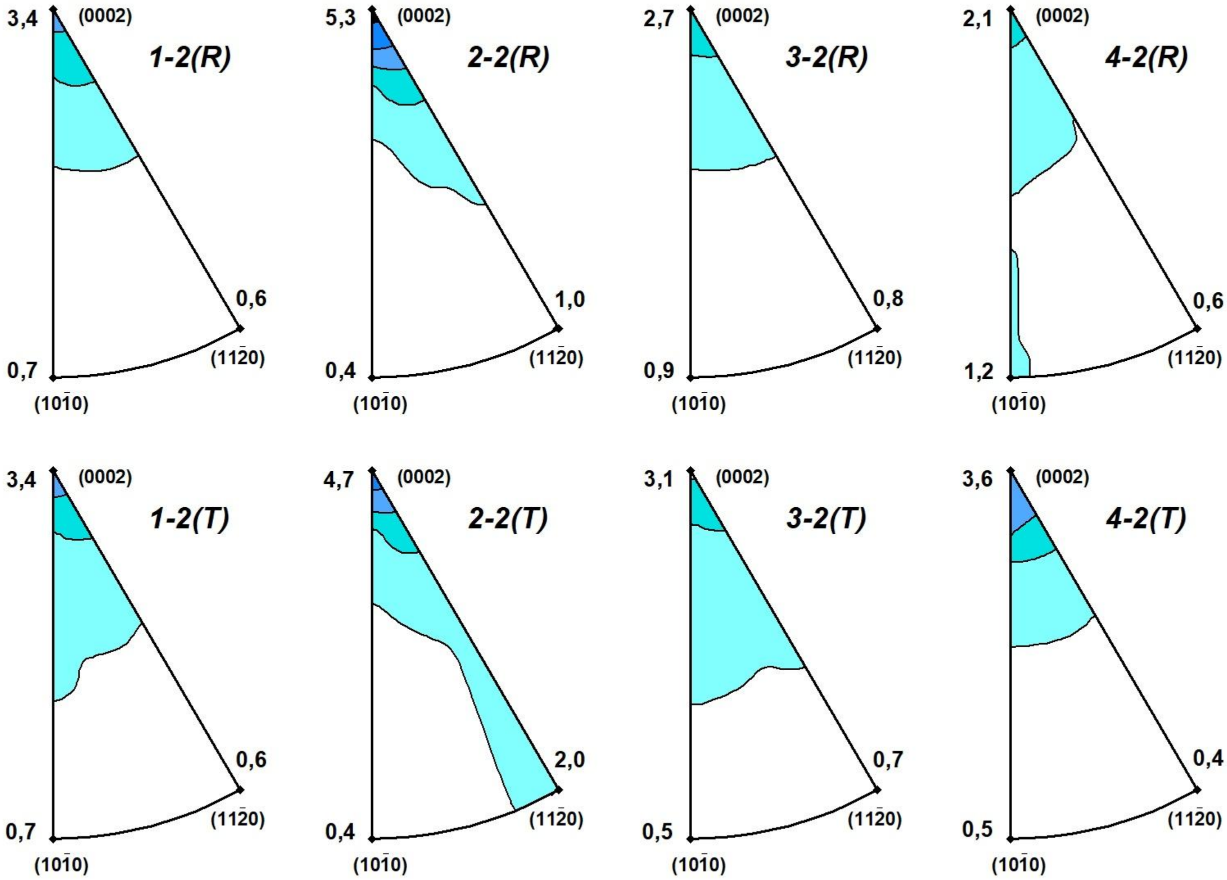
The study of the tube metal structure (Fig. 5) has shown that it was fine-grained (13…19 μm) after heat treatment. Hereditary orientation of new grains in the rolling direction was observed. In order to increase reduction ratio in the subsequent pass, it is necessary to correct heating conditions and mode, i. e. ensure achievement of more complete recrystallization.

This issue requires a separate experiment with extension of the exposure time in furnace or rising heating temperature which is largely determined by the reduction ratio in the previous rerolling step and the possibility of implementation of higher reduction ratio in the next step. Share of the radial texture component has decreased in all specimens taken from tubes of intermediate sizes.

Table 2

Mechanical properties, Kearns coefficients, CSR and fabrication characteristics of Ti-3Al-2.5V alloy tubes at various stages of stock processing

Size, mm	State	Sample mark	Mechanical properties $\sigma_{\text{в}}$, MPa	Mechanical properties $\sigma_{0,2}$, MPa	Mechanical properties δ, %	Kearns coefficients f_r	Kearns coefficients f_t	CSR	Flattening/ expansion testing
∅85×20	after extrusion	1-1	751	608	20	0.463	0.493	–	–
∅86×20		2-1	760	654	18	0.462	0.558	–	–
∅50×8	TREX tube	1-2	656	527	23-24	0.45-0.47	0.43-0.42	–	–
								–	–
∅38×5	TREX tube	2-2	675-680	533-539	18.6-18.8	0.46	0.44	–	–
		3-2	658-661	537-542	19.2-20.1	0.48	0.40	–	–
		4-2	670-674	560-563	22-23.3	0.47	0.39	–	–
∅25×3.2	intermediate size after thermal treatment in vacuum		958-962	860-872	16-17	0.42	0.50	–	–
∅17.5×1.7	intermediate size after thermal treatment in vacuum		957	858	12	–	–	–	–
			963	856	14.4	0.43-0.44	0.45-0.51	1.2	–
			907	794	14.4	0.45-0.49	0.44-0.45	0.9-1.2	–
Finished tubes									
∅15.8×0.8	finished tube with 50% reduction at the last processing pass		948-967	842-880	14.2-15.4	0.38	0.42	1.3	unsatisfactory/unsatisfactory
			952-958	875-879	14-14.8	0.39	0.40	1.4	satisfactory/satisfactory
			944-949	842-867	14.6-15.2	0.41	0.40	1.3-1.4	satisfactory/satisfactory
∅15.8×0.8	finished tube with 80% reduction at the last pass	1-3	958-960	871-878	16.8-19.6	0.563-0.585	0.359-0.382	1.7-1.8	satisfactory/satisfactory
		2-3	914-920	809-911	18.4-19	0.585	0.382	1.7-1.8	satisfactory/satisfactory
∅12.7×0.889	finished tube	4-3	956-962	849-851	18-18.4	0.56	0.38	1.4-1.5	satisfactory/satisfactory
∅9.53×0.483	finished tube		961-974	774-809	12.5-13.5	–	–	1.68-2.02	satisfactory/satisfactory
∅6.95×0.402	finished tube		870-899	733-772	12.5-15	–	–	1.64-2.49	satisfactory/satisfactory
Requirements of normative documents			862-979	≥724	≥14	–	–	1.3-3.5	–



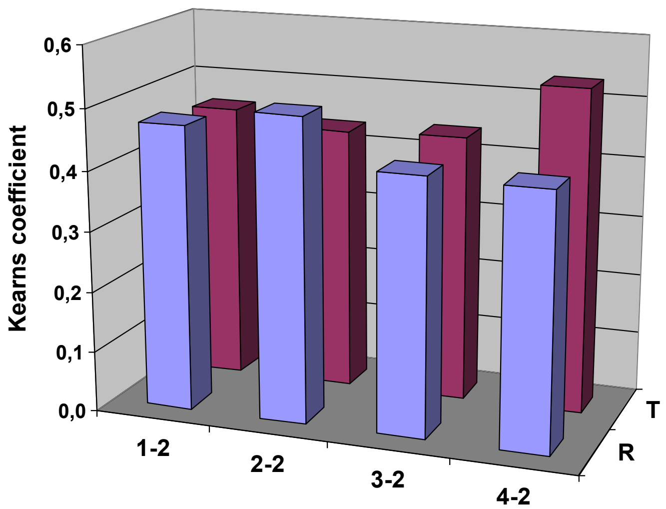
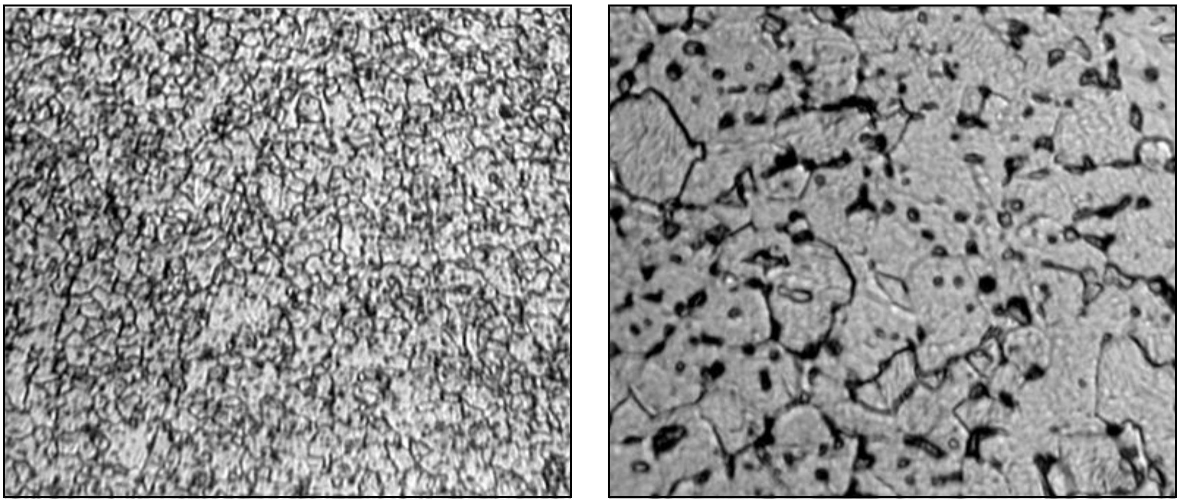


Fig. 3. IPFs of the specimens prepared from TREX tubes (upper figures) and the diagram of corresponding values of the texture parameter (R for radial direction, T for tangential direction)

This indicates the need of correcting deformation schedules and the working tool design (see Table 2).

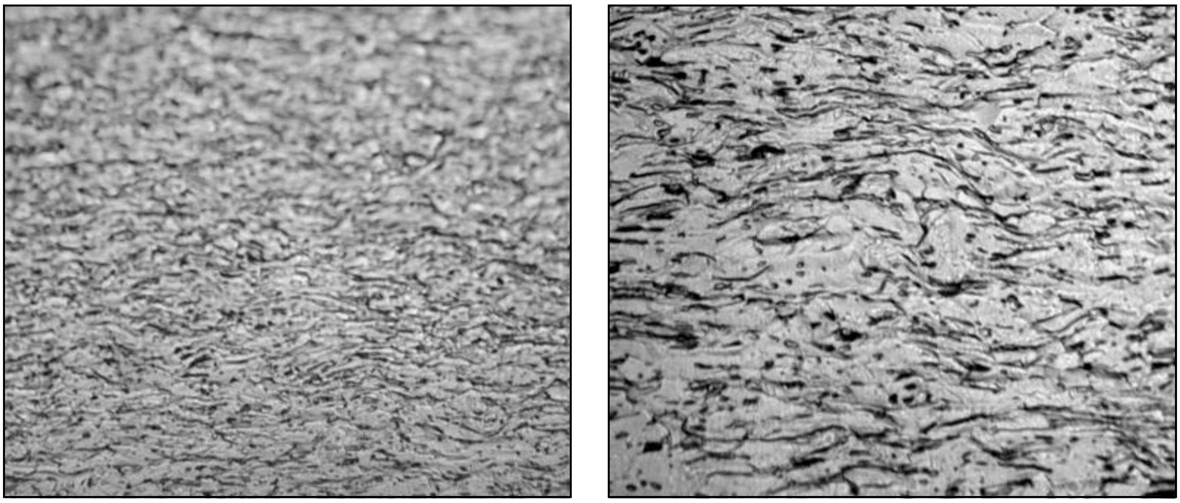
The CSR values after heat treatment are low: 0.9-1.2 (cf. required 1.3-3.5) which is also confirmed by the study results: increased tensile strength and yield strength, and the tubes did not pass flattening and expansion tests.

Analysis of working schedules and wall to diameter reduction ratios as well as formation of textures has shown that the reduction ratios should be increased in passes. In addition, it is necessary to further analyze how reduction behaves in the deformation zone length, i.e. distribution of wall and diameter reductions along the length of the deformation zone. As it follows from the experience of zirconium tube production, to ensure formation of radial texture, reduction of the tube wall should prevail (Q-factor or the ratio of wall reduction to diameter reduction should not be less than 3) [10].



a (×100) *b (×500)*

Fig. 4. Microstructure in the TREX tubes of Ti-3A-2.5V alloy at the size of ∅38.1×5.36 mm



a (×100) *b (×500)*

Fig. 5. Microstructure in Ti-3Al-2.5V alloy tubes at an intermediate size of ∅17.5×1.7 mm

Intensities of X-ray lines were examined and distributions of the pole density, P_{hkl}, and values of the Kerns textural parameter (*f*) in finished tubes of ∅19.0×0.991, ∅15.8×0.8 and ∅12.7×0.889 mm sizes were calculated and presented in Table 2.

This also indicates an incorrectly chosen working schedules and a low *Q*-factor. It should be at least 3 in the last pass at a higher total reduction ratio.

Studies of microstructure in tubes of finished sizes (Fig. 6) have shown that stress relief conducted at a temperature of 390 ^{0}C for 30 min leaves the grains elongated in the rolling direction.

Comprehensive study of finished tubes of various sizes was performed.

Judging from the data in Table 2, mechanical properties of the finished tubes are at the upper limit of requirements, have low CSR and low percentage of radial texture. These data suggest that it is necessary to regulate conditions of deformation and heat treatment in the manufacture of tubes.

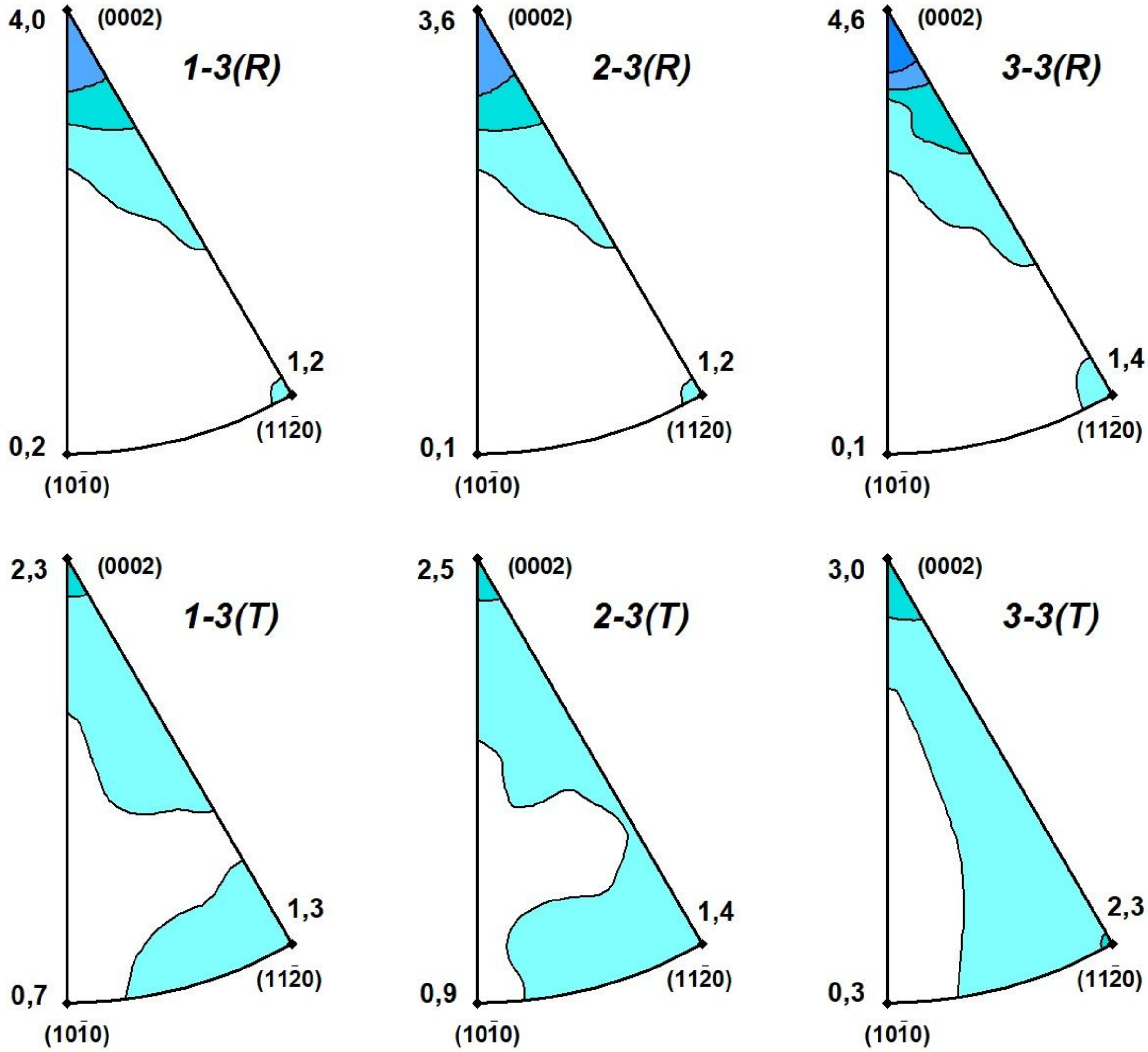
An experiment was performed to increase reduction ratio in the last rolling pass up to 80%. At low reduction ratios of 45…55%, tubes have a low share of the radial component at a level of f_r = 0.38…0.41; an increase in reduction ratio to 80…85% increases share of the radial texture component up to f_t = 0.56…0.59.

IPFs in tube specimens and a diagram of the corresponding values of texture parameters for the delivery condition of finished tubes rolled at high reduction ratios in the last pass are presented in Fig. 7.

Fig. 6. Microstructure of tubes of finished ∅12.7×0.889 mm size after stress-relief heat treatment (×500)

Radial texture prevails (from $f_r = 0.563$ to $f_r = 0.585$) in all tubes rolled at a high reduction ratio in the last pass. Tangential texture was reduced to $f_t = 0.359$ and $f_t = 0.382$.

Mechanical properties, compression strain ratios (CSR), results of flattening and expansion tests of tubes in a stress-relieved delivery condition are presented in Table 2. A trend of growth of radial texture content and an increase in CSR value are observed.



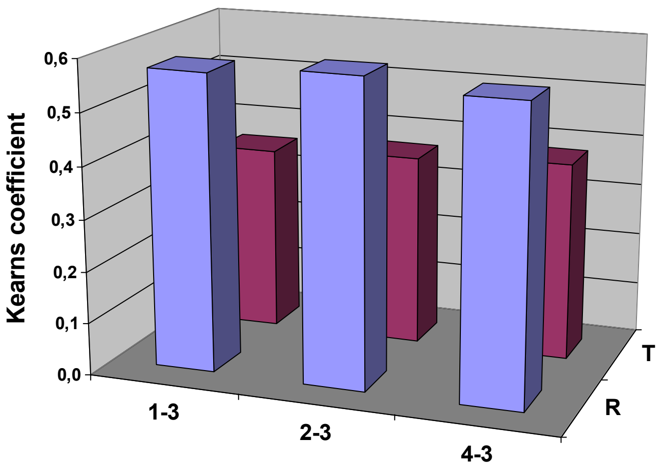


Fig. 7. IPFs for specimens of finished size tubes (upper figures) and the diagram of corresponding texture parameter values (R for radial direction, T for tangential direction)

CONCLUSIONS

Held research conducted texture, structure and properties of tubes of titanium alloy Ti-3Al-2.5V at all stages of manufacture. In the process of research, the following has been established:

1. The main texture is formed in tubes at the stage of hot working by extrusion with a greater percentage of the tangential texture component.
2. The stock in already textured condition is fed to further tube processing steps which affects texture formation during subsequent working.
3. The texture changes slightly in the first cold working passes and most significantly in the last passes. To ensure maximum amount of radial texture in tubes, the total reduction ratio in passes and the ratio of wall to diameter reductions (*Q*-factor) are important. The reduction ratio should be increased, especially in the last passes, up to 75…85%.
4. Heat treatment (stress-relief anneal) practically does not change texture in tubes.
5. Increase in the tube metal ductility occurs with an increase in the amount of radial texture and, accordingly, in the CSR coefficient.

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ОСОБЕННОСТИ ФОРМИРОВАНИЯ КРИСТАЛЛОГРАФИЧЕСКОЙ ТЕКСТУРЫ И СВОЙСТВ В ТИТАНОВОМ СПЛАВЕ Ti-3Al-2.5V ПРИ ИЗГОТОВЛЕНИИ ТРУБ

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Рассмотрены процессы текстурообразования на всех технологических этапах изготовления труб. Установлено, что на стадии горячей деформации и изготовления трэкс труб формируются тангенциальная и радиальная текстуры, причем доля тангенциальной составляющей текстуры больше. Определено влияние основных факторов технологического процесса на формирование текстуры и свойств. Установлены условия образования максимального количества радиальной текстуры в трубах, что обеспечивает повышение эксплуатационных свойств труб. Для создания в трубах максимального количества радиальной текстуры важными являются общая степень деформации в проходах и соотношение деформации по стенке и диаметру (фактор *Q*). Следует увеличить общую степень деформации, особенно на последних проходах до 75…85%. Термическая обработка (отжиг для снятий напряжений) практически не изменяет текстуру труб.

ОСОБЛИВОСТІ ФОРМУВАННЯ КРИСТАЛОГРАФІЧНОЇ ТЕКСТУРИ І ВЛАСТИВОСТЕЙ В ТИТАНОВОМУ СПЛАВІ Ti-3Al-2.5V ПРИ ВИГОТОВЛЕННІ ТРУБ

В.С. Вахрушева, Н.В. Грузін, Д.Г. Малихін

Розглянуто процеси текстуроутворення на всіх технологічних етапах виготовлення труб. Встановлено, що на стадії гарячій деформації і виготовлення трекс труб формуються тангенціальна та радіальна текстури, причому частка тангенціальної текстури більша. Визначено вплив основних факторів технологічного процесу на формування текстури та властивостей. Встановлені умови утворення максимальної кількості радіальної текстури в трубах, що забезпечує підвищення експлуатаційних властивостей труб. Для створення в трубах максимальної кількості радіальної текстури важливими є загальна міра деформації, а також співвідношення деформації по стінці та діаметру (фактор *Q*). Слід збільшити загальну міру деформації, особливо на останніх проходах до 75…85%. Термічна обробка (відпал для зняття напружень) практично не змінює текстури труб.