A DEFORMATION MODE IN A COLD ROLLING CONDITION TO PROVIDE THE NECESSARY TEXTURE OF THE TI-3Al-2.5V ALLOY

Introduction. Titanium alloy products are already used in vital parts of mechanisms, instruments and devices not only in the nuclear, aerospace and shipbuilding industries, but also in the elements of transmission and braking systems [1, 2], ground electric transport engines [3] and even for premium tube connections for oil and gas industry [4]. Titanium is a ground electric transport engines [3] and even for premium the elements of transmission and braking systems [1, 2], the nuclear, aerospace and shipbuilding industries, but also in vital parts of mechanisms, instruments and devices not only in the nuclear, aerospace and shipbuilding industries, but also in the elements of transmission and braking systems [1, 2], ground electric transport engines [3] and even for premium tube connections for oil and gas industry [4]. Titanium is a ground electric transport engines [3] and even for premium tube connections for oil and gas industry [4].

Its mechanical processing is rather difficult [7]; therefore, researchers increasingly frequently resort to new methods for forming the mat surface [8]. Titanium and its β-structure alloys having a body-centered cubic lattice are more ductile. Among all possible factors [9, 10], namely anisotropy of metal texture has a great influence on reliability of products made of zirconium and titanium alloys [11, 12]. From behind in the standards for this type of product, special attention is paid to the requirements to ensure the presence of the required type of texture.

Taking into account the need to ensure uninterrupted and safe operation of the abovementioned units, the requirements for the microstructure of the tube’s material made of titanium and zirconium alloys are among the highest [13]. Based on these, studies in this field are relevant and necessary [14, 15].

The micro- and macrostructure of the material of titanium [16] and zirconium tubes, subjected to deformation in cold pilger mills, is influenced not only by hot working parameters and the distribution of reduction value over the cross-section area from passage to passage, but also distribution of the ratio of true deformation along the wall thickness to true deformation along the mean diameter (Q-factor) both along the passes...
and along the deformation cone of each individual pass. This fact requires the creation of separate, specialized modes of tubes’ deformation in cold pilger mills, aimed at creating the required structure of tubes made of alloys based on titanium and zirconium.

It is also necessary to study the influence of the working tool calibration parameters on the character of the Q-factor distribution along the deformation cone. Ideally, the Q-factor should increase along the deformation cone or fluctuate around a certain value. But too large values of the Q-factor are also unacceptable since they lead to deterioration in mechanical properties.

Analytical research survey. All factors that directly (or indirectly) affect the change in the ratio of the reduction in the wall thickness to the reduction in the mean diameter, affect the nature of the Q-factor distribution along the cone. It is known that the character of the Q-factor distribution is influenced by the chosen distribution law of the tube wall thickness along the deformation cone reduction zone. It is also necessary to use mandrels with curvilinear generatrix of its surface. These mandrels have a greater degree of deformation control than conical ones.

The parameters of tool calibration during cold pilger rolling, which affect the change in the deformation mode along the deformation cone, include the total reduction along the wall, the total reduction along the average diameter, the taper of the mandrel with a curved generatrix, the initial taper of the groove ridge, the degree of steepness of the groove ridge, the degree of steepness forming the mandrel and the amount of metal feed.

The objective of this work is to study the influence of the calibration tool parameters set during cold pilger rolling—mandrel initial taper with curvilinear generant, initial sweep taper of the gauge crest, slope degree of the gauge crest, the degree of steepness forming the mandrel and the amount of metal feed.

Methods. Currently, tubes made of titanium alloys, in particular, tubes made of allotropic, as technically pure titanium, titanium alloy Ti-3Al-2.5V are widely used. At relatively low temperatures in this alloy, the α-phase with hexagonal close-packed lattice is prevalent [12] (Fig. 1).

It is understood that the energy spent on the process of crystal deformation by twinning is half the energy causing the slip deformation process. To start the deformation when applying force to the crystal in the direction parallel to the base pole (Fig. 1, position 1), it is necessary to create the amount of strain twice as big as that in the perpendicular direction. When forces are applied in the direction perpendicular to the base pole, the deformation proceeds mainly through sliding (Fig. 1).

Initially, after hot rolling, Ti-3-2.5V alloy tubes have a random grain orientation. After cold pilger rolling, depending on the Q-factor distribution from pass to pass (and along the deformation cone in each pass), it is possible to obtain either a radial orientation (high Q-factor value cold rolling), or a tangential orientation (low Q-factor value cold rolling).

The tubes with radial metal structure have the following advantages: increased endurance strength, increased plasticity, higher value of the yield stress at a given value of the ultimate stress limit and higher ductility.

In the standard for tubulars AMS 4945, among other things, the methodology (and requirements) for measuring the relative reduction ratio (in another way — compressive deformation ratio, CSR) is outlined. CSR testing is used to determine the texture of tube metal. If the tests obtained small values of CSR, then the tube has a tangential structure, at high values it has a radial structure.

The value of the Q2-factor per pass should increase from the first to the last when the reductions are distributed over the cold rolling passes. The value of the Q2-factor per pass is calculated as the ratio of the true deformations along the wall to the true deformation along the mean diameter per pass. Calculation of the calibration and all deformation parameters of the cold rolling of pipes was based on a number of existing theoretical and empirical dependencies included in the generally accepted method of their calculation.

To perform the calculations, a software product “Q-Factor. Cold pilger tube rolling” (Fig. 2) was developed. In the case of calculating a deformation tool using some dependencies from the method of proportional reduction calibration, the nature of the Q-factor distribution along the deformation cone can be controlled by the slope degree of the mandrel and the gauge crest sweep and initial taper of the mandrel and the gauge crest sweep. The calculations were performed according to the scheme shown in Fig. 2:

1) input of initial data, such as tube and workpiece parameters, deformation cone parameters (including the length of the deformation cone zones), and so on;
2) calculation of intermediate data, such as the maximum allowable initial taper, the gap between the mandrel cylinder and the inner side of the tube, and others;
3) calculation of mandrel diameters D(i) in the control sections;
4) calculation of the wall thickness S(i) in the control sections;
5) calculation of the gauge diameter Dg (i.e. the deformation cone) in the control sections;
6) calculation of intermediate deformation data D(i-1), S(i-1), S(i), Dg(i), and others;
7) calculation of the Q-factor distribution along the deformation cone.
It is important to create such deformation modes in which the Q-factor distribution along the cone generators around a certain value (above the value of the Q-factor equal to one) or increases along the cone.

For the computational research on the Q-factor distribution along the deformation cone, the following routes of the CRT-55 mill were selected:

- option A, route is 38.1 x 2.2 – 32.1 x 2. The relative reduction over the cross-sectional area $\varepsilon_2$ is equal to 23.78 %. The relative reduction in diameter $\varepsilon_d$ is 15.75 %. The relative reduction along the wall thickness $\varepsilon_l$ is equal to 9.09 %. The greatest possible initial taper of the mandrel 2tg$\alpha$ is 0.0231. The Q-factor per pass $Q_{2tg\alpha}$ is 0.97;

- option B, route is 38.1 x 2.2 – 32.1 x 1.47. The relative reduction over the cross-sectional area $\varepsilon_2$ is equal to 42.99 %. The relative reduction in diameter $\varepsilon_d$ is 15.75 %. The relative reduction along the wall thickness $\varepsilon_l$ is equal to 33.18 %. The maximum possible initial taper of the mandrel 2tg$\alpha$ is 0.0101.

When calculating the Q-factor distribution according to calibration option A, the following values of the initial taper of the mandrel generant were selected: 2 tg$\alpha$ is 0.005, 2 tg$\alpha$ is 0.01, and 2 tg$\alpha$ is 0.008 and 2 tg$\alpha$ is 0.01.

The results of calculations are shown in the graph (Fig. 3).

As can be seen from the graphs (Figs. 3 and 4), in all cases, already in the last third of the compression zone, the Q-factor possesses values close to zero, since there is hardly any deformation along the wall thickness, but further plugless rolling in the pre-finishing zone continues.

The calculation results are shown in the graph (Fig. 3).

Calculations performed to assess the impact of the feed rate on the Q-factor distribution along the reduction and pre-finishing zones of deformation cone (mandrel slope degree $n$ is 2.5; crest slope degree $n_c$ is 2.5; 2tg$\alpha$ is 0.01, the route is 38.1 x 2.2 – 32.1 x 1.47) showed that when the feed value changes in the range from 2 to 8 mm, the curves describing changes in the Q-factor along the reduction and pre-finishing zones of deformation cone, practically merge.

So, the influence of the feed in the studied range of parameters can be neglected when choosing the deformation conditions to ensure the required type of texture.
The studies carried out have shown that by choosing the rolling route and changing the tool calibration parameters and, as a consequence, the parameters of metal deformation during cold pilger rolling of tubes, it is possible to achieve a Q-factor distribution close to equilibrium along the reduction zone only in the wall reduction zone.

At the same time in all investigated cases there is a drop in the Q-factor values below one in the pre-finishing zone, the length of which is one and a half lengths of the linear displacement. This leads to an increase in the metal consumption rate and therefore at a high price, it leads to a decrease in the economic indicators of production.

The article presents a comparative study on the Q-factor distribution with and without the presence of the pre-finishing zone in the zone of length distribution with and without the presence of the pre-finishing zone, in the zone of length distribution with and without the presence of a pre-finishing zone, in the zone of length distribution with and without the presence of the pre-finishing zone.

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The graph (Fig. 7) shows that in this case the necessary conditions are created to ensure an equilibrium, in size not less than one, Q-factor along the entire length of the deformation zone. The drop in this value at the end of the reduction zone is insignificant and can be neglected.

The proposed deformation mode has been tested in production conditions. At the same time, an increased yield was observed.

It should be noted that the described approach somewhat reduces the productivity of cold rolling mills, since the tube deformation process must be carried out with a reduced feed rate.

However, a decrease in productivity leads to significantly lower production costs than an increase in the metal consumption ratio.

Thus, it is possible to create conditions for obtaining the required type of metal texture of cold-rolled tubes from titanium alloy Ti-3Al-2.5V by selecting the parameters of rolling route and mandrel initial taper with curvilinear generant, slope degree of the gauge crest and mandrel.

The results obtained make it possible, by changing the rolling route and tool calibration parameters for cold-rolling tube mills [17, 18] to select the conditions for obtaining the required type of metal texture of cold-rolled tubes made of titanium alloy Ti-3-2.5V, and also to expand its use in the national economy [19, 20].

Conclusions.

1. It is shown that feed values changes in the range from 2 to 8 mm (when the mandrel slope degree equals to 2.5, crest slope degree n is 2.5, the value of two tga is 0.01, for the route 38.1 - 2.2 - 2.1 - 1.47) virtually do not affect the nature and value of the Q-factor distribution along zones of reduction and pre-finishing of the deformation zone.

2. A method is proposed for calibrating the tool for cold pilger rolling of pipes, which allows us, by changing the rolling route (or for the current route), to select rational values of the initial taper of the mandrel with a curved generatrix, the degree of slope of the groove ridge and mandrel, and to create conditions for obtaining the required type of metal texture of cold-rolled pipes titanium alloy Ti-3-2.5V.

3. The most significant effect on obtaining a Q-factor close to equilibrium distribution along the length of the wall reduction and pre-finishing zones was the use of the slope degree n equal to 1.5, i.e., lower values of the crest slope degree.

4. It is shown by calculation that certain action provide more efficient conditions of deformation for obtaining the required metal texture of tubes, namely:

- removing the pre-finishing zone and at the same time increasing the length of the crimping zone;
- applying compression along the wall thickness, not exceeding half the tolerance for the wall thickness at the end of the crimping zone;
- choosing rational calibration parameters using the software product “Q-Factor. Cold pilger tube rolling”.

Conditions are created to ensure the values of the Q-factor close to uniform, and not less than one along the entire length of the deformation zone.

The deformation mode developed according to the proposed method of tool calibration of the cold-rolling mill of pipes was tested in production conditions. At the same time, an increased yield was observed.

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Fig. 7. Effect of presence of pre-finishing zone on Q-factor distribution along the deformation zone (n is 1.5, tga is 0.005, the route is 38.1 - 2.2 - 2.1 - 1.47): 1 – with pre-finishing zone (l_{μ Σ}=0.005, the route is 38.1 - 2.2 - 2.1 - 1.47); 2 – calibration without pre-finishing zone but with special one at the end of reduction zone where the value of reduction along the wall thickness was chosen not more than half of the wall thickness tolerance
Режим деформации в стане холодной прокатки труб для обеспечения необходимой текстуры сплава Ti-3Al-2.5V

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Мета. Забезпечення умов деформації для отримання необхідної текс тури труб зі сплаву Ti-3Al-2.5V на основі вибору рациональних значень параметрів калібрування інструменту – калібірів і опрацювок при холодній пільгertonій прокатці труб для необхідного розподілу Q-фактора конуса деформації.

Методика. Базувалася на існуючій залежності, яка описує вплив розподілу відносного суттєвого діаметра труб зі сплаву Ti-3Al-2.5V на розподіл Q-фактора конуса деформації у прокатці труб. Розрахунок калібрування розраховувався на основі рівняння M-hourг калібрування труб з інструментом Ti-3Al-2.5V, який використовується при холодній пільгertonій прокатці труб зі сплаву Ti-3Al-2.5V.

Результати. Досліджувалий розрахунковим способом вплив початкової конусності опрацювок на розподіл Q-фактора конуса деформації у прокатці труб зі сплаву Ti-3Al-2.5V. Розрахунок калібрування труб з інструментом Ti-3Al-2.5V, який використовується при холодній пільгertonій прокатці труб зі сплаву Ti-3Al-2.5V, був проведенний на основі рівняння M-hourг калібрування труб з інструментом Ti-3Al-2.5V, який використовується при холодній пільгertonій прокатці труб зі сплаву Ti-3Al-2.5V.
основе вибора рациональних значення параметрів калибровки інструмента — калибров і оправки при холодній пильгерній прокатці труб для вимогового розподілення Q-фактора вдоль конуса деформації.

Методика. Базувалася на існуючій зависимості, яка описує вплив розподілення відносних обжаттів вдоль конуса деформації по товщині стінки і по середньому діаметру на розподілення величини Q-фактора. Розрахунок калибрування і розрахунок відштовхувальних параметрів процесу холодної прокатки труб базувався на ряді існуючих теоретичних та емпіричних залежностей, входящих в об’ємприняті адаптовані методи їх розрахунку. Для виконання розрахунків створено програмний продукт «Q-Factor. Cold pilger tube rolling».

Результати. Існували розрахунковим способом вплив начальної конусності оправки з криволінійною об’ємразерек гребня калибра, степені крутні зоною образуючої оправки і образуючої розшарування гребня калибра, величини подачі на розподілення Q-фактора вдоль зон обжаття і предотделки конуса деформації. Наібільше значиме вплив на отримання близького до робочого розподілення Q-фактора по ділянці зон обжаття стінки і предотделки конуса деформації.

Наукова новизна. Поставлені нові знання про вплив калібровки інструмента холодної пильгерній прокатці труб на розподілення Q-фактора вдоль конуса деформації.

Практична значимість. Поставлені і опробовані з поліпшеними результатами метод інтенсивного розподілення режимів деформування з удосконаленою зонною обжаття стінки і без зони предваритільної отримки. Цей метод забезпечує близьке до робочого розподілення Q-фактора вдоль зони обжаття стінки деформаційного конуса і з значеннями більше одиниці. Одержані результати дають можливість підбирати з використанням програмного продукту «Q-Factor. Cold pilger tube rolling» умови для отримання необхідної типу текстури метала холоднокатаных труб з титанового сплаву Ti-3Al-2.5V.  

Ключові слова: холоднокатаные трубы, титановый сплав Ti-3Al-2.5V, тип текстури, начальная конусность оправки, Q-фактор

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