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

Purpose. Providing deformation conditions in order to obtain the required texture of pipes made of Ti-3Al-2.5V alloy based on the choice of rational values of the tool calibration parameters – gauges and mandrels during cold pilger rolling of pipes for the required Q-factor distribution along the deformation cone.

Methodology. The research methods were based on the existing dependence, which describes the influence of the distribution of the ratio of true reduction along the deformation cone along the wall thickness and along the average diameter, on the distribution of the Q-factor value. The calculation of calibration and all deformation parameters of the Cold Reducing tube process was based on a number of existing theoretical and empirical dependencies included in the generally accepted and adapted methods of their computation. To perform calculations, we created the software product "Q-Factor. Cold pilger tube rolling".

Findings. The influence of the initial taper of the mandrel with a curvilinear generatrix and the sweep of the groove ridge, the degrees of steepness of the generatrix of the mandrel and the sweep of the groove ridge, the value of the feed on the distribution of the Q-factor along the compression zones and pre-finishing of the deformation cone were investigated by calculation. The use of slope degrees *n*, equal to 1.5, i. e. less than values of crest slope degree had the most significant effect on obtaining the Q-factor close to equilibrium distribution along the length of wall reduction and pre-finishing zones. A method of multifactor calibration of the tool for cold pilger rolling of pipes is proposed, which makes it possible to select rational values of the initial taper of the mandrel with a curved generatrix, the degree of slope of the sweep of the groove ridge and the mandrel, and to create conditions in the wall compression zone for obtaining the required type of metal texture of cold-rolled pipes made of titanium alloy Ti-3-2.5V. At the same time, in the prefabrication zone, in all investigated cases, there is a drop in the Q-factor values below one.

Originality. New knowledge was obtained about the influence of the rolling route and the full complex of tool calibration parameters in the process of cold pilger rolling of pipes on the distribution of the Q-factor along the length of the deformation cone.

Practical value. A method for determining the modes of deformation with an extended compression zone and without a pre-finishing zone is proposed and tested with positive results. This method provides a distribution of the Q-factor along the reduction zone of the deformation cone which is close to uniform distribution and with values above one. The results obtained make it possible to select the conditions for obtaining the required type of metal texture of cold-rolled pipes from titanium alloy Ti-3Al-2.5V using the software product "Q-Factor. Cold pilger tube rolling".

Keywords: *cold-rolled tubes, titanium alloy Ti-3Al-2.5V, texture type, mandrel initial taper, Q-factor*

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 polymorphic metal [5, 6]. Mechanical anisotropy is observed in α-titanium with hexagonal close-packed latitude due to a limited number of sliding planes.

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 latitude 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

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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 generant 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 sweep, 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 and mandrel generant and also metal feed rate to the Q-factor distribution along the deformation cone for various typical routes of tube production from an alloy based on titanium Ti-3Al-2.5V.

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 latitude 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).

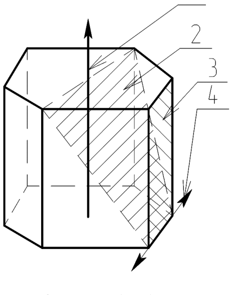

Fig. 1. Orientation of crystal planes in a hexagonal close-packed latitude:

1 – basal pole; 2 – pyramidal sliding plane; 3 – prismatic sliding plane; 4 – general sliding direction

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 Q_Σ-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 Q_Σ-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_x in the control sections;

4) calculation of the wall thickness S_x in the control sections;

5) calculation of the gauge diameter D_x (i. e. the deformation cone) in the control sections;

6) calculation of intermediate deformation data $D_{x-\Delta x}$; $S_{x-\Delta x}$ and others;

7) calculation of the Q-factor distribution along the deformation cone.

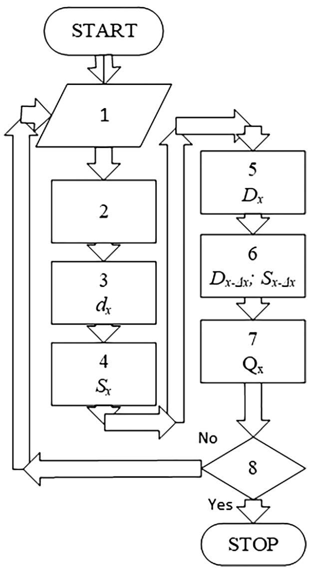

Fig. 2. Settlement scheme

It is important to create such deformation modes in which the Q-factor distribution along the cone hovers 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 38.1·2.2 – 32.1·2. The relative reduction over the cross-sectional area $\varepsilon\Sigma$ is equal to 23.78 %. The relative reduction in diameter ε_D is 15.75 %. The relative reduction along the wall thickness ε_S is equal to 9.09 %. The greatest possible initial taper of the mandrel 2 tgα is 0.0231. The Q-factor per pass Q_Σ is 0.97;
- option B, route is 38.1·2.2 – 32.1·1.47. The relative reduction over the cross-sectional area ε_Σ is equal to 42.99 %. The relative reduction in diameter ε_D is 15.75 %. The relative reduction along the wall thickness ε_S is equal to 33.18 %. The maximum possible initial taper of the mandrel 2tgα is 0.0101. The Q-factor per pass Q_Σ is 1.078.

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 tgα is 0.005, 2 tgα is 0.01, and 2 tgα is 0.012.

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

Calculation of the Q-factor distribution according to calibration option B was performed with the following initial taper values: 2 tgα is equal to 0.005, 2 tgα is 0.08 and 2 tgα is 0.01. The calculation results are shown in the graph (Fig. 4).

As can be seen from the graphs (Figs. 3 and 4), in all cases, already in the final sections of the deformation 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.

In the variant of the rolling route A, when Q_Σ is 0.97, i.e. there are initially unfavorable rolling conditions, the Q-factor value in the cross-section of the deformation cone falls below one in the last third of the reduction zone at 2 tgα equal to 0.005, and in the case of calibration with 2 tgα equal to 0.012, it drops already at the end of the first third of the compression zone.

At 2 tgα equal to 0.008 and 2 tgα equal to 0.01, the Q-factor values drops below one in the 44th and 45th cross-sections, respectively. The most favorable rolling conditions are observed when 2 tgα is equal to 0.005, but Q_Σ takes values below one also at the end of the deformation zone (in the 47th cross-section). Q-factor values close to zero are observed already in the first quarter of the pre-finishing zone in all cases of calibrations for a given route. At the same time, in the sections starting from 47, Q-factor values are below 1.

Impact assessment results of the slope degree of the roll crest on the Q-factor distribution are shown in Figs. 5 and 6.

Impact assessment of the of the slope degree of the roll crest on the Q-factor distribution along the reduction and pre-finishing zones of deformation cone was also performed for rolling routes A, B. Herewith crest slope degree varied from 1.5 to 2.5.

Impact analysis of the slope degree of the gauge crest generant on the Q-factor distribution along the reduction and pre-finishing zones of deformation cone (Figs. 5 and 6) shows that it is preferable to use slope degrees *n* equal to 1.5, i.e., lower values of the crest slope degree. In such a case, Q-factor distribution becomes close to equilibrium along the deformation cone length, and Q-factor decrease below one occurs in later cross-sections. In this situation the metal is in more favorable conditions in terms of providing the required type of tube metal structure.

Calculations performed to assess the impact of the feed rate on Q-factor distribution along the reduction and pre-finishing zones of deformation cone (mandrel slope degree *n* is 2.5; crest slope degree n_r is 2.5; 2tgα is 0.01, the route is 38.1 × × 2.2–2.1 · 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.

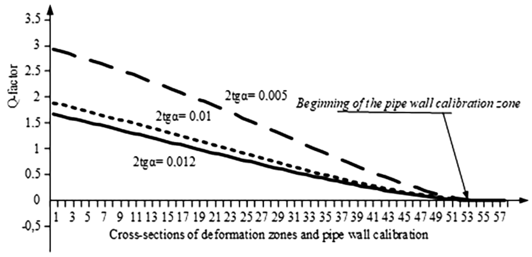

Fig. 3. Influence of the initial taper of the mandrel with curvilinear generant on the Q-factor distribution along the reduction and pre-finishing zones of deformation cone (the mandrel slope degree n equal to 2.5, the route is 38.1 · 2.2–32.1 · 2, the feed rate m is 5 mm)

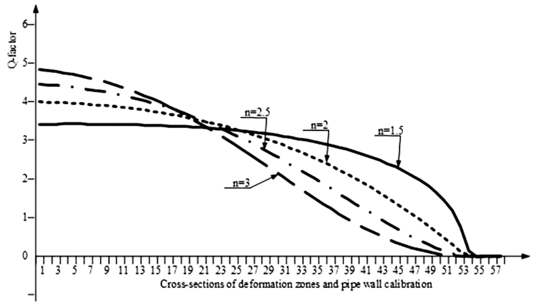

Fig. 5. Influence of the slope degree of the gauge crest generant on the Q-factor distribution along zones of reduction and pre-finishing of the deformation con (2 tgα is 0.01, the route is 38.1 · 2.2–32.1 · 2, the feed rate m is 5 mm)

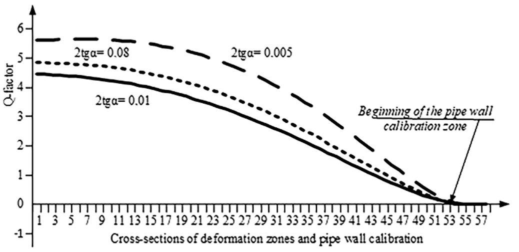

Fig. 4. Influence of the slope degree of the mandrel with curvilinear generant on the Q-factor distribution along zones of reduction and pre-finishing of the deformation cone (the slope degree n is 1.5, the route is 38.1 · 2.2–32.1 · 1.47, the feed rate m is 5 mm)

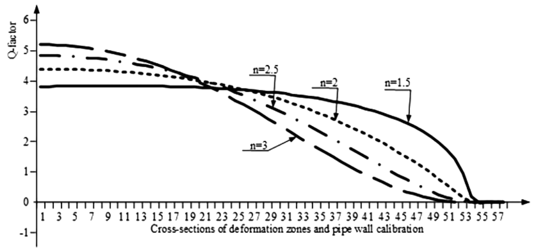

Fig. 6. Influence of the slope degree of the gauge crest generant on the Q-factor distribution along zones of reduction and pre-finishing of the deformation con (2 tgα is 0.008, the calibration type is calibration of proportional reductions, the route is 38.1 · 2.2–32.1 · 1.47, the feed rate m is 5 mm)

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 working tool calibration (caliber sweep) (Fig. 7). In the absence of pre-finishing zone, in the zone of length $1.5m\mu_{\Sigma}$, located after the reduction zone and before the beginning of the diameter calibration zone, the value of reduction along the wall thickness was chosen not more than half of the tolerance for the wall thickness. This condition is introduced in order to ensure the required tube accuracy along the wall thickness. Such a calibration technique has been tested in practice and is quite sufficient to obtain tubes with reasonable accuracy in wall thickness at a calculated value of the feed rate.

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].

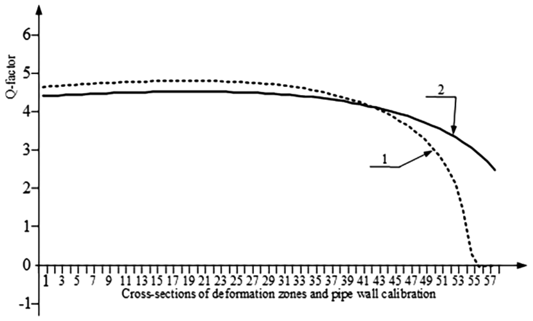

Fig. 7. Effect of the presence of pre-finishing zone on Q-factor distribution along the deformation cone (n is 1.5, 2 tgα is 0.005, the route is 38.1 · 2.2–32.1 · 1.47):

1 – with pre-finishing zone ($l = 1.5m\mu_{\Sigma}$); 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

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_r is 2.5, the value of 2 tgα 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 cone.

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.

References.

1. Taran, I. A., & Klymenko, I. Y. (2014). Innovative mathematical tools for benchmarking transmissions of transport vehicles. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (3), 76-81.

2. Protsiv, V. V., & Monya, A. G., (2003). Experimental determination of characteristics of clutch of mine locomotive under the braking conditions. *Metallurgicheskaya i Gornorudnaya Promyshlennost, 2*, 95-97. Retrieved from https://www.researchgate.net/publication/293546988_Experimental_determination_ocharacteristics_of_clutch_of_mine_locomotive_under_the_braking_conditions.

3. Bohdanov, O., Protsiv, V., Derbaba, V., & Patsera, S. (2020). Model of surface roughness in turning of shafts of traction motors of electric cars. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (1), 41-45. https://doi.org/10.33271/nvngu/2020-1/041.

4. Protsiv, V., Ziborov, K., & Fedoriachenko, S. (2015).Test load envelope of semi – premium O&G pipe coupling with bayonet locks. *New Developments in Mining Engineering 2015: Theoretical and Practical Solutions of Mineral Resources Mining*, 261-264. https://doi.org/10.1201/b19901-46.

5. Zhanal, P., Harcuba, P., Šmilauerová, J., Stráský, J., Janeček, M., Smola, B., & Hájek, M. (2015). Phase Transformations in Ti-15Mo Investigated by in situ Electrical Resistance. *Acta Physica Polonica*, *128*(4), 779-783.

6. Karpov, V., & Nosko, O. (2018). The effect of hydrogen on the properties of polymorphic metals during thermal cycling near the polymorphism temperature. *Theory and practice of metallurgy*, (11), 62-70.

7. Zhuravel, O., Derbaba, V., Protsiv, V., & Patsera, S. (2019). Interrelation between shearing angles of external and internal friction during chip formation. *Solid State Phenomena*, *291*, 193-203. https://doi.org/10.4028/www.scientific.net/SSP.291.193.

8. Didyk, R. P., & Kozechko, V. A. (2016). Forming of multilayer constructions by explosion welding. *Chernye Metally*, (7), 66-70. Retrieved from http://rudmet.com/journal/1546/article/26547/.

9 Grigorenko, V. U., & Pilipenko, S. V. (2008). Variation in wall thickness of cold-rolled pipe. *Steel in Translation, 38*(9), 775-776. https://doi.org/10.3103/S0967091208090209.

10. Zhixin Li, Zhan Mei, Kun Guo, & Tao Huang (2017). Texture Development of Ti-3Al-2.5V Titanium Alloy Tubes. *Rare Metal Materials and Engineering, 11*, 3169-3175. https://doi.org/10.1016/S1875-5372(18).

11. Zhang, H. Q., Wang, X. F., Wie, B. L., & Li, H. (2017). Effect of tooling design on the cold pilgering behavior of zircaloy tube. *The International Journal of Advanced Manufacturing Technology, 92*, 2169-2183. Retrieved from https://link.springer.com/article/10.1007/s00170-017-0250-0.

12. Vakhrusheva, V. S., Hruzin, N. V., & Malykhin, D. G. (2019). Thermal and fast reactor materials features of formation of crystallographic texture and properties in Ti-3Al-2.5V titanium alloy during tubes manufacture. *Problems of atomic science and technology, 5*(123), 105-112. Retrieved from https://vant.kipt.kharkov.ua/article/vant_2019_5/article_2019_5_105.pdf.

13. Mishchenko, A. V. (2019). State and development trends of the production of cold-rolled pipes from titanium-based alloys. *Metal and casting of Ukraine, 3-4*, 310-311.

14. Krishna Aditya, Y. V. (2014). Complexity of pilgering in nuclear applications. *Journal of Engineering Research and Applications, 4*(11), 41-46.

15. Gospodinov, D., Ferdinandov, N., & Dimitrov, S. (2016). Classification, properties and application of titanium and its alloys. *Proceedings of University of Ruse, 55*(2), 27-32.

16. Kosmatsky, Ya. I., Filyaeva, E. A., Fokin, N. V., & Yakovleva, K. Yu. (2016). Determination of the technological feasibility of manufacturing a new type of seamless pipes trex titanium alloy TI-3AL-2.5V. *Quality in material processing, 2*(6), 15-22.

17. Jaiveer Singh, S. Mahesh, Shomic Roya, Gulshan Kumar, Srivastava, D., Dey, G. K., ..., & Samajdara, L. (2016). A miniature physical simulator for pilgering. *Journal of Materials Processing Technology, 237*, 126-138. https://doi.org/10.1016/j.jmatprotec.2016.06.009.

18. Grigorenko, V. U., Pilipenko, S. V., & Golovchenko, A. P. (2015). *The development of the parameters in the process of cold pilger rolling of pipes and calibration of the tool*: *monograph*. Dnipropetrovsk: Thresholds.

19. Taran, I. A., & Klymenko, I. Yu. (2013). Transfer ratio of double-split transmissions in case of planetary gear input. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 60-66.

20. Pivnyak, G., Samusia, V., Oksen, Y., & Radiuk, M. (2015). Efficiency increase of heat pump technology for waste heat recovery in coal mines. In: *New Developments in Mining Engineering: Theoretical and Practical Solutions of Mineral Resources Mining*, CRC Press, 1-4. eBook ISBN 9780429225758.

Режим деформації в стані холодної прокатки труб для забезпечення необхідної текстури сплаву Ti-3Al-2.5V

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Мета. Забезпечення умов деформації для отримання необхідної текстури труб зі сплаву Ti-3Al-2.5V на основі вибору раціональних значень параметрів калібрування інструменту – калібрів і оправок при холодній пільгерній прокатці труб для необхідного розподілу Q-фактора уздовж конуса деформації.

Методика. Базувалася на існуючій залежності, що описує вплив розподілу відношення істинних обтиснень уздовж конуса деформації по товщині стінки й по середньому діаметру, на розподіл величини Q-фактора. Розрахунок калібрування й розрахунок усіх деформаційних параметрів процесу холодної прокатки труб базувався на низці існуючих теоретичних і емпіричних залежностей, що входять до загальноприйнятих адаптованих методів їх розрахунку. Для виконання розрахунків створили програмний продукт «Q-Factor. Cold pilger tube rolling».

Результати. Досліджували розрахунковим способом вплив початкової конусності оправок із криволінійною твірною та розгортки гребеня калібру, ступенів крутизни утворюючої оправки та утворюючої розгортки гребеня калібру, величини подачі на розподіл Q-фактора уздовж зон обтиску й предобробки конуса деформації. Найбільш значний вплив на отримання близької до рівномірного розподілу Q-фактора по довжині зон обтиску стінки та предобробки зробило застосування ступенів крутизни n, рівних 1,5, тобто менших значень ступеня крутизни гребеня**.** Запропоновано метод багатофакторного підбірочного калібрування інструменту холодної пільгерної прокатки труб, що дозволяє підібрати оптимальні значення початкової конусності оправки із криволінійною твірною, ступеня крутизни розгортки гребеня калібру та оправки і створити в зоні обтиску стінки умови для отримання необхідного типу текстури металу холоднокатаних труб із титанового сплаву Ti-3-2.5V. При цьому, у зоні предобробки, у всіх досліджених випадках спостерігається падіння значень Q-фактора нижче одиниці.

Наукова новизна. Отримані нові знання щодо впливу маршруту прокатки й повного комплексу параметрів калібрування інструменту у процесі холодної пільгерної прокатки труб на розподіл Q-фактора по довжині конуса деформації.

Практична значимість. Запропоновано й випробувано з позитивними результатами метод багатофакторного підбіркового визначення режимів деформування з подовженою зоною обтиску стінки й без зони попередньої обробки. Цей метод забезпечує близький до рівномірного розподіл «Q-фактора» уздовж зони обтиску стінки деформаційного конуса і зі значеннями вище одиниці. Отримані результати дають можливість підбирати з використанням програмного продукту «Q-Factor. Cold pilger tube rolling» умови для отримання необхідного типу текстури металу холоднокатаних труб із титанового сплаву Ti-3Al-2.5V.

Ключові слова: *холоднокатані труби***,** *титановий сплав Ti-3Al-2.5V, тип текстури, початкова конусність оправки, Q-фактор*

Режим деформации в стане холодной прокатки труб для обеспечения необходимой текстуры сплава Ti-3Al-2.5V

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Цель. Обеспечение условий деформации для получения необходимой текстуры труб из сплава Ti-3Al-2.5V на основе выбора рациональных значений параметров калибровки инструмента – калибров и оправки при холодной пильгерной прокатке труб для требуемого распределения Q-фактора вдоль конуса деформации.

Методика. Базировалась на существующей зависимости, которая описывает влияние распределения отношения истинных обжатий вдоль конуса деформации по толщине стенки и по среднему диаметру на распределение величины Q-фактора. Расчет калибровки и расчет всех деформационных параметров процесса холодной прокатки труб базировался на ряде существующих теоретических и эмпирических зависимостей, входящих в общепринятые адаптированные методы их расчета. Для выполнения расчетов создали программный продукт «Q-Factor. Cold pilger tube rolling».

Результаты. Исследовали расчетным способом влияние начальной конусности оправки с криволинейной образующей и развертки гребня калибра, степеней крутизны образующей оправки и образующей развертки гребня калибра, величины подачи на распределение Q-фактора вдоль зон обжатия и предотделки конуса деформации. Наиболее значительное влияние на получение близкого к равномерному распределению Q-фактора по длине зон обжатия стенки и предотделки оказало применение степеней крутизны n, равных 1,5, т.е. меньших значений степени крутизны гребня.

Предложен метод многофакторной калибровки инструмента холодной пильгерной прокатки труб, который позволяет подобрать рациональные значения начальной конусности оправки с криволинейной образующей, степени крутизны развертки гребня калибра и оправки и создать в зоне обжатия стенки условия для получения необходимого типа текстуры металла холоднокатаных труб из титанового сплава Ti-3-2.5V. При этом, в зоне предотделки, во всех исследованных случаях наблюдается падение значений Q-фактора ниже единицы.

Научная новизна. Получены новые знания о влиянии маршрута прокатки и полного комплекса параметров калибровки инструмента в процессе холодной пильгерной прокатки труб на распределение Q-фактора по длине конуса деформации.

Практическая значимость. Предложен и опробован с положительными результатами метод многофакторного подборочного определения режимов деформирования с удлиненной зоной обжатия стенки и без зоны предварительной отделки. Этот метод обеспечивает близкое к равномерному распределение «Q-фактора» вдоль зоны обжатия стенки деформационного конуса и со значениями выше единицы. Полученные результаты дают возможность подбирать с использованием программного продукта «Q-Factor. Cold pilger tube rolling» условия для получения необходимого типа текстуры металла холоднокатаных труб из титанового сплава Ti-3Al-2.5V.

Ключевые слова: *холоднокатаные трубы, титановый сплав Ti-3Al-2.5V, тип текстуры, начальная конусность оправки, Q-фактор*

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