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MICROSTRUCTURES AND MECHANICAL PROPERTIES OF COLD ROLLED PIPES WITH INCREASED SMALL DEFORMATION

Purpose. Experimental study on microstructure, mechanical properties of pipe diversity on a new type of cold rolling pipe, which has the ability to perform different modes of supply and rotation.

Methodology. Research method is an experimental one on modern industrial equipment using modern devices. The study was conducted when rolling pipes made of steel 08Cr18Mn10Ti on the CRP 6-20 mills. Rolling route is often 25 × 2.5 mm → 16 × × 1.5 mm, which is often used in production. Rolling was carried out on the CRP 6-20 mills in four modes of feed and rotation: mode 1 – feed is performed before the forward stroke, and rotation before the return stroke of the stand; mode 2 – the feed is performed before the forward stroke, and the rotation before the forward and reverse stroke of the stand; mode 3 – feeding is performed in the front and rear position of the stand and rotation in the rear position of the stand; mode 4 – feed and turn are performed before the forward and reverse of the stand.

Findings. Metallographic studies on microstructures showed that for mode 1, the grain size on the outer surface of the pipes is less than on the inner surface. The difference reaches the value of 1–2 points. For mode 4, the opposite is true. The size of the grains on the outer surface of the pipes is larger than on the inner surface. The difference reaches the value of 1–2 points. This can be explained by the fact that in mode 1 most of the compression is performed in the forward stroke rather than in reverse stroke. And in mode 4, these crimps are close in value and smaller than in a forward stroke in mode 2.

Originality. New experimental industrial data have been obtained for the first time on the state-of-the-art cold rolling mill for small-diameter pipes made of microstructures of riveted steel 08Cr18Mn10Ti in cross-sectional and longitudinal sections of the pipes on the outer and inner surfaces of the pipes and between them for four possible feeding and turning modes. For the first time, experimental industrial data on the values of strength limit, yield strength and ultimate elongation at four feeding and turning modes have been obtained as well.

Practical value. The obtained experimental industrial data from a set of quality parameters of pipes – metal microstructure, mechanical properties, transverse differences in pipe packages allow one to choose modes of supply and rotation in the production of cold-formed pipes to ensure compliance with regulated quality parameters of supply and rotation pipes.

Keywords: *cold deformed pipes, steel 08Cr18Mn10Ti, supply, turn, microstructures, mechanical properties*

Introduction. In recent years, deliveries have been increasing of cold-formed pipes made of corrosion-resistant steels according to EN norms and according to American ASTM standards, in which the requirements for the accuracy of the pipe wall are high, for example, according to the requirements of EN 10216-5 and ASTM A213/A213M for export from Ukraine. Cold pilger rolling of pipes is applied both for use in the production of pipes from corrosion-resistant steels, titanium-based alloys [1] and in the production of pipes from carbon grades of steel. Research is conducted with the aim of improving production technologies to ensure the regulated norms and standards of requirements for pipe accuracy [2] and microstructure [3]. Foreign researchers are also engaged in similar issues [4, 5].

In Ukraine, a large number of looms of types CRP 32, CRP 55, CRP 90 are operated, in which the feed is performed before the forward stroke, and the turn is performed before the reverse stroke. Such states are already physically and morally obsolete. Ukrainian enterprises engaged in the production of cold-formed pipes began to purchase new modern cold rolling mills for various pipes.

New imported cold rolling mills of types CRP 6-20, CRP 2-40, CRP 10-45, KPV25, LG20, operating in Ukraine, have an ability to perform the process according to various variants of feeding and turning modes [6, 7]. These states have the main technical characteristics given in Tables 1, 2 and 3.

The new modern CRP 20-45 type is also used in the production of pipes made of corrosion-resistant steels. The new state-of-the-art KPW-25LC in Ukraine is also used for the production of pipes from titanium-based alloys [1].

These machines (in particular, the CRP 40-8 machine) have an ability to perform all possible modes of feeding and turning.

The CRP 40-8 machine can only perform rolling mode with feed and turn before the forward and reverse motion of the cage.

Studies performed by a number of researchers have shown positive results in increasing the accuracy in the production of tubes when applying rolling modes with feed and turn in front of the forward and reverse moves of the cage. These experiments were carried out on the latest CRP mills with modernized distribution and feed mechanisms, which provide the possibility of performing feed and rotation before the forward and reverse moves of the cage, and at modern mills which provide the possibility of performing various modes of feed and return combinations in the design of feed-return mechanisms.

Experiments showed the advantages of rolling modes with feed and turning before forward and reverse strokes in comparison with the rolling process with feed before the forward stroke and turning before the reverse one.

Four main modes of operation are used in rolling mills.

Mode 1 – feeding is performed before the forward movement, and the turn is performed before the reverse movement of the cage.

Mode 2 – feeding is performed before the forward movement, and the turn is performed before the forward and reverse movements of the cage.

Mode 3 – feeding is performed in the front and rear positions of the cage, and the turn is performed in the rear position of the cage.

Mode 4 – feeding and rotation are performed before the forward and reverse movements of the cage.

The microstructures, mechanical properties and cross-sectional heterogeneity of the tubes are the most studied for deformation, where the feed is performed before the forward stroke, and the rotation is performed before the reverse stroke of the cage. This mode of deformation has been used for many years.

Modes 2 and 3 are hardly used, and mode *4*, which has significant advantages in terms of pipe accuracy (with relatively equal performance of the modes), is not widely used. The peculiarities of the application of the second and third regimes have been studied much less.

Table 1

The main technical characteristics of the modern mill KPW-25LC

Parameters	Unit of meas.	Value
the maximum outer diameter of the workpiece	mm	38
workpiece wall thickness	mm	1.0–6.0
outer diameter of rolled pipes	mm	8–30
wall thickness of rolled pipes	mm	0.5–4.5
minimum length of the workpiece	mm	1500
maximum length of the workpiece	mm	8000
speed value	double moves per minute	from 15 to 320
feed rate	mm	0–8

Table 2

The main technical characteristics of the modern mill CRP 40-8

Parameters	Unit of meas.	Value
the maximum outer diameter of the workpiece	mm	24–42
workpiece wall thickness	mm	1.4–6.0
outer diameter of rolled pipes	mm	12–35
wall thickness of rolled pipes	mm	0.5–4.0
minimum length of the workpiece	mm	1500
maximum length of the workpiece	mm	8000
speed value	double moves per minute	from 20 to 220
feed rate	mm	1.5–19.0

Table 3

The main technical characteristics of the modern mill CRP 6-20

Parameters	Unit of meas	Value
the maximum outer diameter of the workpiece	mm	12–26
workpiece wall thickness	mm	0.8–3.0
outer diameter of rolled pipes	mm	6.0–20.0
wall thickness of rolled pipes	mm	0.25–2.0
minimum length of the workpiece	mm	2000
maximum length of the workpiece	mm	6500
speed value	double moves per minute	from 60 to 140
feed rate	mm	1.5–5.0

The above-mentioned rolling modes with different options for feeding and turning differ in the amounts of feeding before the forward and reverse moves of the cage. This leads to the use of different values of fineness of deformation for a full cycle of deformation in a double stroke of the cage.

The fineness of deformation is the number of crimps of each cross-section of the metal of the pipe during the total crimping during the period of passage through the total cell of the deformation zone (working cone of deformation).

Determining the fineness of the deformation was studied only for the first mode of execution of feed and rotation. The influence of feeding and turning modes and, accordingly, the fineness of deformation on the complex of pipe quality parameters (microstructure, mechanical properties and cross-sectional heterogeneity of pipes) have not yet been sufficiently studied and require additional research.

This knowledge is required for the design of pipe production technologies, ensuring the accuracy of wall thickness and pipe diameter, mechanical properties of pipe steels, including microstructure requirements, regulated by modern norms and standards.

Analytical research survey. The process of cold rolling of pipes is presented in Fig. 1.

Pipe rolling on the CRP mill is carried out with rolls having a variable cross section on a fixed conical mandrel (Fig. 1). The initial size of the groove corresponds to the outer diameter of the workpiece, and the final size corresponds to the outer diameter of the pipe. On the caliber, in accordance with the sequence of operations, the following sections are distinguished: feed throat; reduction; crimping; calibration relative to the wall; diameter calibration; yawn turn. The CRP condition tool is roll-mounted gauges and a mandrel.

Conical mandrels and mandrels with a curved design are used. Conical mandrels are usually used during the produc-

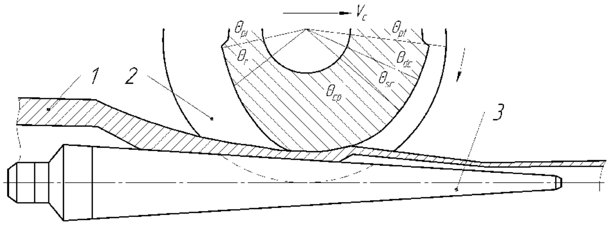

Fig. 1. Scheme of the process of cold periodic roll rolling on a cold mill rolling mill:

1 – pipe; 2 – caliber; 3 – mandrel; θ_{pi} – feed throat; θ_r – reduction section; θ_{cp} – crimping section; θ_{sc} – calibration area relative to the wall; θ_{dc} – calibration area relative to the diameter; θ_{pt} – turn throat; V_c – the forward speed of the cage during the straight movement of the cage tion of pipes from carbon grade steel for general purpose. Mandrels with a curved shape are used during the production of pipes, mainly from stainless steel grades and from titanium alloys. The main characteristic of the mandrel is its taper (Fig. 1).

In the total center of deformation obtained during the movement of the cage, which is called the working cone (Figs. 1 and 2), pipe reduction (area l_r), wall thickness compression (area l_{cp}), wall calibration (pretreatment area l_{sc}), and diameter calibration are carried out (area l_{dc}).

One rolling cycle takes place during a double move of the cage, which includes forward and reverse moves.

Due to the rotation of the pipe around its axis, the releases are rolled out. The total length of all zones (l_Σ) is determined as a part of the expanded length of the circle with the radius of the initial circle of the leading gears.

In one rolling cycle (double pass) a section of the finished pipe is obtained

$$l = m\mu_\Sigma,$$

where μ_Σ is the total coefficient of elongation per cycle.

Each cross-section of the blank pipe is successively pressed *n* times (where *n* is the fineness of the deformation) with rolls from the dimensions of the blank to the dimensions of the finished pipe.

Deformation of each section is carried out both during forward and reverse movements of the cage. During the direct execution of the mode 1 rolling process, the main deformation is carried out on the forward stroke of the cage (approximately 70 percent of the total deformation), and on the reverse stroke, only the release is deformed (30 percent of the total deformation). In modes 2, 3, and 4, the ratio of deformations performed in the forward and reverse movements of the cage changes. The fineness of the deformation also changes.

An important feature of the process of cold rolling of pipes is that in one working cycle deformation can be carried out from 75 to 95 % of the initial section of the workpiece, that is, the process can be carried out with 14-fold or even 18-fold extraction. But the process is mainly carried out with deformations that are two to three times smaller. This is due to the need to ensure the absence of microcracks in the metal in order to ensure its operability under conditions of various mechanical loads and other influences on the metal of the manufactured pipe.

Scientists from different countries constantly pay attention to the research on cold rolling of seamless pipes. This, first of all, concerns changes in microstructures [8, 9] during cold rolling of seamless stainless steel pipes, the ratio of deformations on the wall and on the diameter of the pipe (Q-factor) [3], the creation of nanostructures on the inner surface of pipes [10], improved tubes-shells of nuclear fuel [11, 12], creation of new types of microstructures [13], high-energy processing of metals [14].

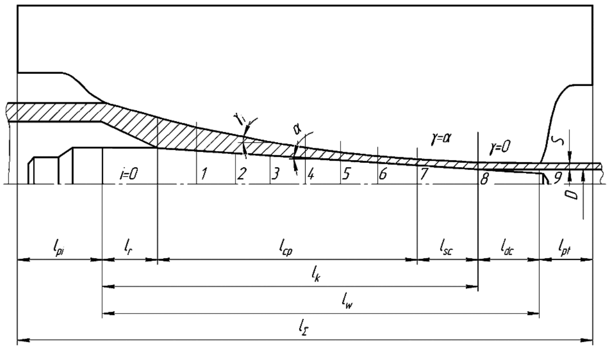

Fig. 2. Rolling cone in the mill of cold rolling of pipes:

l_{pi} – the length of the feed throat section; l_r – the length of the reduction section; l_{cp} – the length of the wall crimping section; l_{sc} – the length of the wall calibration section; l_{dc} – the length of the diameter calibration section; l_{pt} – the length of the throat of the pipe; l_k – the length of the conical part of the mandrel; l_w – length of the working part of the rolling cone; l_Σ – groove deployment length

This is related to the problems of increasing the performance of pipes in various units of responsible purpose.

The authors of this paper previously conducted studies on the influence of four modes of deformation on the cross-sectional heterogeneity of pipes. Comparable experimental data on the level of diversity for all four feeding and turning modes were obtained. It is shown that from the point of view of obtaining low values of the cross-sectional diversity of the finished pipes, the modes where the feeding and turning are performed before the forward and before the reverse moves of the cage are effective. Moreover, the feed is two times smaller than in the process, where it is performed on a straight line, and turning on the reverse course of the cage. A similar conclusion was obtained for the ovality and waviness of the pipes.

The purpose of this work is to obtain a set of results of experimental studies with regulated norms according to the standards of the quality parameters of cold-formed pipes (microstructures, mechanical properties of 08Cr18Mn10Ti steel and cross-sectional heterogeneity of pipes in production packages of pipes for four options for performing feeding and turning during cold rolling. Moreover, the cross-sectional heterogeneity in pipe packages were investigated in the most rational mode of deformation, where feeding and turning are performed before the forward and reverse movement of the cage.

Methodology. The study on the microstructure, mechanical properties and cross-sectional heterogeneity of the pipes was carried out in four possible modes of feeding and rotation.

One of the rolling routes (25 × 2.5 mm → 16 × 1.5 mm), which is often used in production, was chosen for the experiment.

We use steel of grade 08Cr18Mn10Ti as a material for the production of pipes. This is one of the brands that has a wide demand in various industries.

Rolling was carried out on the condition of CRP6 20 mill in four feeding and turning modes (modes 1, 2, 3 and 4).

The task was to obtain images of the metal microstructure in cross-sectional and longitudinal sections of pipes in four feeding and turning modes and to determine their features.

Detection and determination of grain size was carried out by the metallographic method according to GOST 5639-82 “Steels and alloys. Methods of detection and determination of grain size” The following equipment was used for this:

- a grinding machine (sample preparation);
- a device for electrolytic etching (sample preparation);
- vertical metallographic microscope MIM7.

We obtained data on the mechanical properties of the pipe blanks and finished pipes (Tables 4 and 5).

The size of the grain was determined on samples cut according to the drawing below (Fig. 3).

The surface of the sample made for microgrinding according to the drawing shown in Fig. 3, was sharpened on an emery machine with an abrasive wheel. The value of the surface roughness parameter *Ra* did not exceed 2.5 μm according to GOST 2789.

The tensile strength, yield strength, and relative elongation for all four feed and twist modes were found to be close in value. It should be determined that the amount of total draft

Table 4

Mechanical properties of pipes of 25 × 2 mm blanks made of grade 08Cr18Mn10Ti steel

Strength limit, MPa	Yield point, MPa	Relative elongation, %
660	370	45
670	350	45

Table 5

Mechanical properties of finished pipes made of 08Cr18Mn10Ti steel

Rolling mode	Feeding, mm	Mechanical properties		
		Strength limit	Yield point	Relative elongation
		MPa	MPa	%
1	2	1020	89	12
	3	1050	95	13
	4	140	93	12
2	2	1050	97	13
	3	1050	97	13
	4	1030	96	12
3	2 + 2	1050	95	11
	2.5 + 2.5	1090	96	12
	3 + 3	1040	93	13
	3.5 + 3.5	1090	99	12
	4 + 4	1060	93	12
4	2 + 2	1110	96	11
	2.5 + 2.5	1070	98	11
	3 + 3	1060	92	12
	3.5 + 3.5	1070	93	11
	4 + 4	1090	98	10

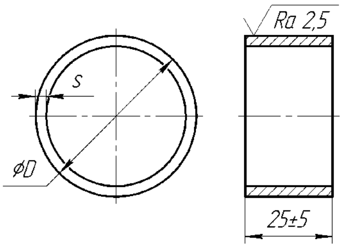

Fig. 3. Drawings of samples:

D – pipe diameter, mm; s – wall thickness

and total crimping along the cross-sectional area were the same for all four modes of feeding and turning. After that, the sample was subjected to grinding on a grinding and polishing machine.

As a result of the research, we obtained pictures of the microstructures presented in Figs. 4–7. Grain sizes were determined as 10–11 points.

From a visual inspection of the shapes and sizes of the grains in the cross-section of the pipe, it is possible to note the tendency of the difference for modes 1 (feed before the forward stroke of 4 mm and rotation before the reverse stroke of the cage) and mode 4 (feed before the forward stroke of 2 mm and rotation, and also before the reverse stroke feed of 2 mm and rotation of the produced tube).

For mode 1, the grain size on the outer surface of the pipes is smaller than on the inner surface. The difference visually reaches 1–2 points (Fig. 4).

For mode 4, the opposite is true. The grain size on the outer surface of the pipes is larger than on the inner surface. The difference reaches 1–2 points (Fig. 7).

This can be explained by the fact that in mode 1, more of the crimping is done during the forward stroke than during the reverse stroke. And in mode 4, these crimps are close in value and smaller than during direct travel in mode 2.

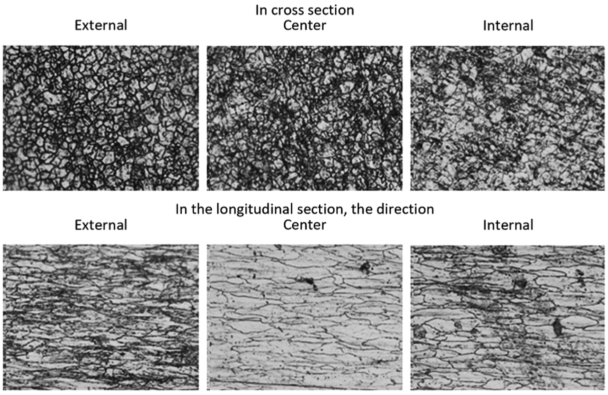

Fig. 4. Microstructure in cross-sectional and longitudinal sections of 08Cr18Mn10Ti steel pipes on the wall thickness. Rolling route 25 × 2.5 mm → 16 × 1.5 mm. Mode 1 – feeding is performed before the forward stroke, and the turn is performed before the reverse stroke of the cage (feeding is 4 mm)

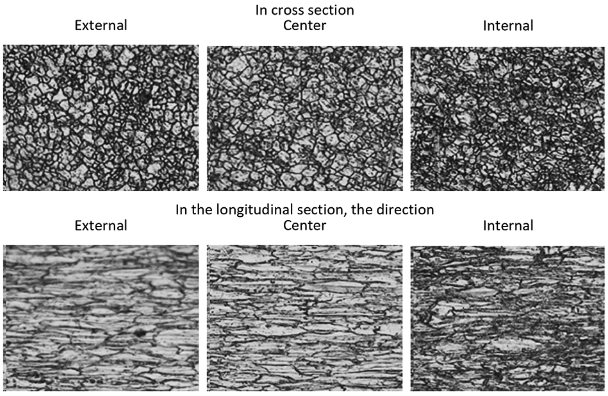

Fig. 5. Microstructure in cross-sectional and longitudinal sections of 08Cr18Mn10Ti steel pipes on the wall thickness. Rolling route 25 × 2.5 mm → 16 × 1.5 mm. Mode 2 – feeding is performed before the forward movement, and turning – before the forward and reverse movements of the cage (feeding is 4 mm)

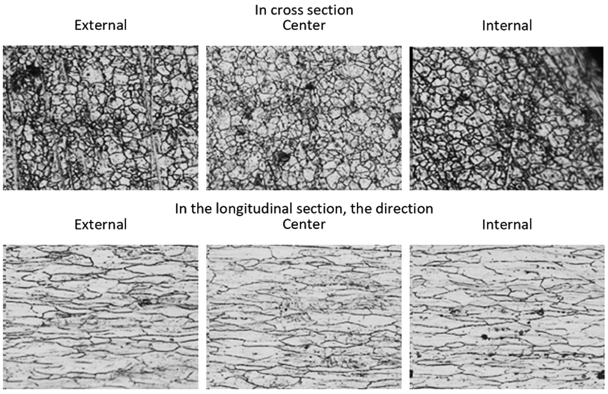

Fig. 6. Microstructure in cross-sectional and longitudinal sections of 08Cr18Mn10Ti steel pipes on the wall thickness. Rolling route 25 × 2.5 mm → 16 × 1.5 mm. Mode 3 – feed is performed in the front and rear positions of the cage, and rotation is performed in the rear position of the cage (feeding is 2 + 2 mm)

The obtained results can be used during the production of other types of pipes [15, 16], including drilling [17] and high-pressure pipelines of hydraulic equipment [18] of stationary and transport machines.

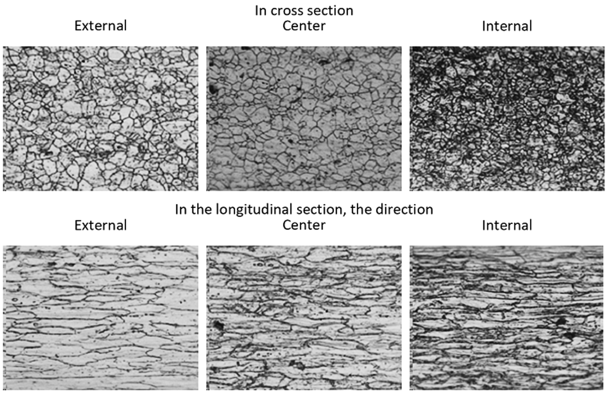

Fig. 7. Microstructure in cross-sectional and longitudinal sections of 08Cr18Mn10Ti steel pipes on the wall thickness. Rolling route 25 × 2.5 mm → 16 × 1.5 mm. Mode 4 – feed and rotation are performed before the forward and reverse movements of the cage (feeding is 2 + 2 mm)

The applied research approaches can be used in related industries [19, 20].

Conclusions. Conducted metallographic studies on microstructures showed that for mode 1, the grain size on the outer surface of the pipes is smaller than on the inner surface. The difference reaches 1–2 points. For mode 4, the opposite is true. The grain size on the outer surface of the pipes is larger than on the inner surface. The difference reaches 1–2 points.

This can be explained by the fact that in mode 1, most of the crimping is performed in the forward direction rather than in the reverse direction. And in mode 4, these crimps are close in value and smaller than in a straight line in mode 1.

The tensile strength, yield strength, and relative elongation for all four feed and twist modes were found to be close in value. The magnitude of the total extraction and the total crimp along the cross-sectional area were the same for all four feeding and turning modes.

References.

1. Mishchenko, O. (2019). Status and trends of development of the production of cold-rolled tubes from titanium alloys. *Metal i litie Ukrainy*, *310-311*(3-4), 58-68. https://doi.org/10.15407/pmach2019.03.058.

2. Mishchenko, O., & Grygorenko, V. (2021). Experimental research of the nature of transverse wall thickness variation in cold rolling of pipes of titanium ALLOY PT-1M. *Modern engineering and innovative technologies*, *15*, Part 2, 20-24. https://doi.org/10.30890/2567-5273.2021-1.

3. Pilipenko, V., Grigorenko, V., Kozechko, V., & Bohdanov, O.A. (2021). Deformation mode in a cold rolling condition to provide the necessary texture of the Ti-3AL-2.5V alloy. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (1), 78-83. https://doi.org/10.33271/nvngu/2021-1/078.

4. McNair, S., Chaharsooghi, A.S., Carnevale, M., Onnela, A., Daugin, J., Cichy, K., ..., & Lunt, A.J.G. (2022). Manufacturing technologies and joining methods of metallic thin-walled pipes for use in high pressure cooling systems. *International Journal of Advanced Manufacturing Technology, 118*(3-4). https://doi.org/10.1007/s00170-021-07982-8.

5. Li, H., Wei, D., Zhang, H., & Li, H. (2019). Texture evolution and controlling of high-strength titanium alloy tube in cold pilgering for properties tailoring. *Journal of Materials Processing Technology, 279*(8), 116520. https://doi.org/10.1016/j.jmatprotec.2019.116520.

6. Cold pilger mills – SMS group GmbH (n.d.). Retrieved from https://www.sms-group.com/plants/all-plants/cold-pilger-mills#:~:text=Cold%20pilgering%20reduces%20the%20need,surface%20roughness%20of%20the%20tubes.

7. Zhangjiagang hengli machinery CO., LTD (n.d.). Retrieved from http://www.henglijx.com/products.html?gclid=Cj0KCQjwpcOTBhCZARIsAEAYLuW8F5DH3QRg7kFESEhI5-XOZ8t2rBrOczBN-JbzzXFctrM6ATba9tV8aAhwrEALw_wcB.

8. Dai, J., Li, W., & Chu, Z. (2020). Microstructure Evolution of Cold Pilgering Stainless Steel Tubes. *Advances in materials science and engineering*. https://doi.org/10.1155/2020/3678980.

9. Chu, Z., Zhang, D., Wei, D., & Shuang, Y. (2017). Study on Microstructure Evolution of Pilger Cold Rolled Seamless Steel Tube. *Advanced Engineering Science*. https://doi.org/10.15961/j.jsuese.201700373.

10. Zhang, H., Zhao, Yi., Wang, Yu., & Zhang, Ch. (2018). Fabrication of nanostructure in inner-surface of AISI 304 stainless steel pipe with surface plastic deformation. *Journal of Materials Science and Technology, 34*(11). https://doi.org/10.1016/j.jmst.2018.05.012.

11. Massey, C.P., Edmondson, P.D., Gussev, M.N., Mao, K., Gräning, T., Nizolek, T.J., ..., & Hoelzer, D.T. (2022). Insights from microstructure and mechanical property comparisons of three pilgered ferritic ODS tubes. *Materials & Design, 213*, 110333. https://doi.org/10.1016/j.matdes.2021.110333.

12. Wu, J., Zhaodandan, M., Xiao, L., Li, W., Hui, W., & Jingjing, L. (2021). Microstructure and twin behavior of Ti-2Al-2.5Zr during cold pilgering. *Materials Research Express, 8*, 096515. https://doi.org/10.1088/2053-1591/ac22c2PAPER.

13. Lemarquis, L., Giroux, P.F., Maskrot, H., Barkia, B., Hercher, O., & Castany, P. (2021). Cold-rolling effects on the microstructure properties of 316L stainless steel parts produced by Laser Powder Bed Fusion (LPBF). *Journal of Materials Research and Technology, 15*, 4725-4736. https://doi.org/10.1016/j.jmrt.2021.10.077.

14. 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/.

15. Protsiv, V., & Grigorenko, V. (2021). Peculiarities of the expansion process in the production technologies of large diameter for main oil and gas pipelines. *Metal and casting of Ukraine, 3*(326), 64-69. https://doi.org/10.15407/steelcast2021.03.087.

16. Golikov, N.I. (2020). Effect of Residual Stress on Crack Development in Longitudinal Welded Joints of a Gas Pipeline. *Procedia Structural Integrity, 30*, 28-32. https://doi.org/10.1016/j.prostr.2020.12.006.

17. 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: Theoretical and Practical Solutions of Mineral Resources Mining*, 261-264. https://doi org/10.1201/b19901-46.

18. Samorodov, V., Bondarenko, A., Taran, I., & Klymenko, I. (2020). Power flows in a hydrostatic-mechanical transmission of a mining locomotive during the braking process. *Transport Problems, 15*(3), 17-28. https://doi.org/10.21307/tp-2020-030.

19. Naumov, V., Taran, I., Litvinova, Z., & Bauer, M. (2020). Optimizing resources of multimodal transport terminal for material flow service. *Sustainability (Switzerland), 12*(16), 6545. https://doi.org/10.3390/su12166545.

20. 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), 193203. https://doi.org/10.4028/www.scientific.net/SSP.291.193.

Мікроструктури й механічні властивості труб холодної прокатки з підвищеною дрібністю деформації

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Мета. Експериментальне дослідження мікроструктури, механічних властивостей різностінності труб на новому сучасному стані холодної прокатки труб, що має можливість виконувати різні режими подачі й повороту.

Методика. Експериментальна, на сучасному промисловому обладнанні з використанням сучасних приладів. Дослідження провели під час прокатки труб зі сталі 08Cr18Mn10Ti на стані ХПТ6-20. Маршрут прокатки 25 × 2,5 мм → 16 × 1,5 мм, що часто використовується у виробництві. Прокатку проводили на стані ХПТ6-20 на чотирьох режимах здійснення подачі й повороту: режим 1 – подачу виконують перед прямим ходом, а поворот перед зворотним ходом кліті; режим 2 – подачу виконують перед прямим ходом, а поворот перед прямим і зворотним ходом кліті; режим 3 – подачу виконують у передньому й задньому положенні кліті, а поворот у задньому положенні кліті; режим 4 – подачу й поворот виконують перед прямим і зворотним ходом кліті.

Результати. Проведені металографічні дослідження мікроструктури показали, що для режиму 1 величина зерен на зовнішній поверхні труб менша, ніж на внутрішній. Різниця досягає величини 1–2 бали. Для режиму 4 все навпаки. Величина зерен на зовнішній поверхні труб більша, ніж на внутрішній. Різниця досягає величини 1–2 бали. Це можливо пояснити тим, що в режимі 1 більша частина обтискання виконується на прямому ходу, ніж на зворотному. А в режимі 4 ці обтиски близькі по своєму значенню й менші, ніж на прямому ходу в режимі 2.

Наукова новизна. Отримані вперше нові експериментальні промислові дані на сучасному стані холодної прокатки труб малих діаметрів з мікроструктур наклепаної сталі 08Cr18Mn10Ti в поперечному й повздовжньому перерізах труб на зовнішній і внутрішній поверхні труб та між ними для чотирьох можливих режимів виконання подачі й повороту. Отримані вперше також експериментальні промислові дані щодо значень межі міцності, межі плину та остаточного подовження на чотирьох режимах виконання подачі й повороту.

Практична значимість. Отримані дослідно-промислові дані щодо комплексу показників якості труб (мікроструктури металу, механічних властивостей, поперечних перепадів у трубних пакетах) дозволяють вибирати режими подачі й повороту під час виробництва холоднодеформованих труб задля гарантованого дотримання регламентованих показників якості труб.

Ключові слова: *холоднодеформовані труби, сталь 08Cr18Mn10Ti, подача, поворот, мікроструктури, механічні властивості*

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