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STRENGTHENING OF PIPE TOOLS FOR COLD ROLLER ROLLING OF CORROSION-RESISTANT PIPES BY APPLICATION OF AMORPHOUS ALLOYS

Lilia Krivchik[1], Tatiana Khokhlova[1], Victoria Pinchuk[1], Artem Holovachov[1], Grigory Srebryansky[1], Victor Nosenko[2], Oleksiy Zagorodniy[3]
[1]National Metallurgical Academy of Ukraine, Dnipro, Ukraine
E-mail: pk@metal.nmetau.edu.ua, tel. (0562)45-31-56;
[2]Institute of Metal Physics G.V. Kurdyumov of the National Academy of Sciences of Ukraine, Kyiv, Ukraine
E-mail: metall@imp.kiev.ua, tel. (044)452-94-72;
[3]Prydniprovska State Academy of Civil Engineering and Architecture, Dnipro, Ukraine
E-mail: postmaster@pgasa.dp.ua, tel. (056)746-10-66

In the production of pipes from corrosion-resistant steels on pipe rolling plants, the current problem is the low stability of the pipe tool. Therefore, the creation of high-performance and durable tools is associated primarily with the production and processing of materials that could withstand harsh working conditions. The technology of heat hardening of the pipe tool for cold roller rolling of corrosion-resistant pipes (rollers and support laths of HPTR mills) from 4Х5МФ1С steel which excludes the third holiday and uses drawing of a covering from powders of amorphous alloys 100…150 μm thick is offered in the work. As a result of the offered technology durability, wear resistance, and also hardness to $HV_{0.1}$ 950–1050 (in comparison with HV 587–690 on existing technology of heat treatment in factory conditions) increases. A wide range of studies of the structure of the coating and industrial tests of rollers and support bars. It is shown that gas-plasma coating of amorphous alloy based on Fe–Si–B system increases the hardness of the tool surface by 1.3–1.6 times and their stability by ~ 30…50%.

INTRODUCTION

Corrosion-resistant steel pipes are widely used in aviation, rocketry, nuclear energy, shipbuilding and other important industries, especially thin-walled pipes. They are manufactured mainly by cold rolling on HPT and CPTR mills. In the process of production of such pipes use a large number of pipe tools, the cost of which is up to 25% of the cost of the entire process in the pipe rolling shop.

The rolling tool of mills of cold and warm rolling of pipes works in very difficult conditions. This is primarily a high (up to several hundred tons) pressure on the metal, alternating loads due to the movement of the instantaneous center of deformation along the axis of rolling, dynamic shocks, etc. Therefore, the stability of the tool must be very high, as it depends on the performance of the mills and the quality of the pipes being pumped.

High stability of the tool is ensured by the quality of the material used for its manufacture and compliance with the manufacturing technology [1].

The quality of pipes when rolling depends on the quality of the rolling tool. Therefore it first of all has to have the exact sizes and a high class of cleanliness of a surface. In addition, it must be durable, have sufficient hardness combined with elasticity and viscosity [2].

The CPTR process was created and used for the production of high-quality high-thickness pipes. Requirements for the geometry of tubular products and the properties of constantly increasing metals are met by using the processes of cold periodic rolling of pipes. The CPTR process, which belongs to these processes, allows to pump pipes of the highest accuracy and quality. It is this fact that contributes to the constant development of the CPTR process and the improvement of units of this type and the modes of deformation that are performed in them [3].

Roller mills of periodic action are intended for cold rolling of pipes with thin and especially thin walls (diameter 4…120 mm, wall thickness 0.03…3.0 mm) sizes: 4…8, 8….15, 15…30, 30…60, and 60…120 (figures indicate the minimum and maximum diameters of the rolled pipes) [4].

Most routes for the production of thin-walled pipes provide two passes on roller mills. This is due to the fact that the rolling mills can not ensure the accuracy of the geometric dimensions of the pipes.

The billet for roller mills are pipes rolled on HPT mills or obtained by drawing. The main characteristic of the standard size of the mill is the range of diameters of the finished pipes that are rolled on this state.

On the HPTR mills, the deforming tool is the rollers, which rest on the support bars and the mandrel (Fig. 1).

They are made of steel 60S2HFA or secondary hardening semi-heat-resistant steel of martensitic class X40CrMoV5-1-1. The hardness of the surface after heat treatment should be in the range of 50–56 HRC [5].

The study of working conditions and the reasons for the release of rollers, mandrels and support bars of cold rolling mills of stainless thin-walled pipes showed that the condition of the normal process of plastic deformation on roller mills is continuous rolling of the roller on the bar surface under rolling friction. In the rolling process, the roller becomes clamped between the bearing surface of the bar and the working cone of the workpiece, while the deformation of the metal is accompanied by the development of significant specific pressures on the contact surface of the roller pins with the support bar [6].

Fig. 1. CPTR mills tool

The main reason for the failure of the support bars is the confessional wear of the working tracks (Fig. 2). The nature of the distribution of wear along the length of the working track of the bar is shown in Fig. 3.

Fig. 2. Confessional wear on the working track of the support bar, developing to a depth of 0.2…0.4 mm

Fig. 3. The nature of the distribution of wear along the length of the working track of the bar

Confessional wear is a process of intensive destruction of surfaces during rolling friction, caused by plastic deformation, with internal stresses, special phenomena of metal fatigue, which is accompanied by the formation of microcracks, cracks, single and group depressions on the friction surface. The main causes of confessional wear of the support bars are significant specific pressures that occur under the action of the transmitted force when rolling the rollers on the working surface of the bars, which reach 1900…2800 MPa (depending on the size of the state), as well as other stresses of the 1st kind [7].

Increasing the stability of the support bars leads to savings in production. Replacement of support laths, in process of their failure, is connected with a stop of a condition for 10…20 min.

The rollers of the CPTR states work in difficult conditions and experience significant specific pressures, shock and cyclic loads.

The main reason for the failure of the rollers is wear on the handle (80%), less often-chipping (Fig. 4) and chipped pins (Fig. 5).

Fig. 4. Wear of rollers on the handle

Fig. 5. Chipping of rollers

The main defect that leads to the failure of all parts of the rolling tool is the chipping of the metal on the work surface. The reason is insufficient contact wear, which in turn is a consequence of reduced hardness [8].

Therefore, the creation of a highly productive and stable in operation pipe tool is associated primarily with the production and processing of materials that could withstand harsh working conditions. High mechanical properties of the tool and its wear resistance are achieved by special doping and heat treatment, but these methods do not always give the desired result. Therefore, it is of some interest to improve and adjust the technology of heat treatment and application of special coatings to increase the wear resistance of the tool [9].

ANALYSIS OF LITERATURE DATA AND PROBLEM STATEMENT

During operation of the tool one of the main types of destruction is wear of the surface. It is established that 85…90% of the tool used in the deformation process fails as a result of wear and only 10…15% for other reasons [10].

Wear – the process of destruction and separation of material from the surface of the tool and (or) the accumulation of its residual deformation during friction, which is manifested in the gradual change of size and (or) shape of the tool (GOST 23002-78). It is associated with the sliding of the workpiece, which is deformed on the surface of the tool in the presence of friction between them.

The main type of strengthening of the pipe tool is the use of thermal and chemical-thermal treatment. We can identify the following main areas of development of processes:

– development of resource-saving technologies of chemical-thermal treatment on the basis of application of vacuum, fluidized bed, cyclic processing in the closed space, sources with high concentration of energy (smoldering, arc discharges, electronic and laser heating, SHS-technologies);

– development of new low-waste technologies for the production of composite metal low-wear and corrosion-resistant coatings, in particular by deposition from the gas phase [11].

Currently, the technologies of this type are widely used ionic chemical-thermal treatment in the glow discharge, in the arc discharge (ionic nitriding, cementation, nitrocementation) and in the fluidized bed (cementation, nitrocementation).

One of the promising ways to increase the stability of the tool is to strengthen it with wear-resistant coatings. Coating is carried out by the method of condensation of the substance with cathodic-ion bombardment (KIB method) on the installations “Bulat” and “Start”, as well as by the method of deposition from the gas phase. Different coatings are applied by the KIB method [12].

Coatings made of titanium nitride and carbide have become the most widespread, and coatings made of molybdenum nitride and carbide, zirconium, vanadium, niobium, and others have been used less frequently. It is not possible to strengthen internal hidden surfaces by the method of KIB. It should also be noted the high initial cost of equipment and the complexity of its operation [12].

Coatings of chromium, titanium, niobium, vanadium, and zirconium carbides are applied by the gas phase deposition method. After coating, the steel tool is subjected to heat treatment, which strengthens it. The method is simple and low cost of devices used [13].

Also known means of applying wear-resistant powder coatings based on nickel and additives of silicon, carbon and chromium on plasma units UPU-3D on various parts in order to increase their wear resistance [14], including nanostructured [15].

A new class of metallurgical materials – amorphous alloys have high mechanical properties: high strength, hardness and wear resistance [16]. The most productive and widespread means of obtaining these materials is quenching from the melt in the form of a tape [17]. The set of properties of these materials would be appropriate to use as coatings, but the amorphous tape of alloys based on iron is plastic and it is difficult to obtain a powder fraction – 100 μm. Usually powders of micro-crystalline and amorphous alloys are produced by spraying the melt [18].

This method is the most productive and economical compared to other methods, but it has two disadvantages: even when spraying with inert gases, the surface of the powder particles contains oxides, particle sizes from 3 to 300 μm, i.e., a very large variation in cooling rate. Oxides degrade the properties of coatings of parts and products, and a large variation in particle size causes anisotropy of their properties due to the difference in cooling rates [19].

These disadvantages can be eliminated by obtaining powders of amorphous alloys by grinding amorphous tape [19]. First, the cooling rate when spraying the melt does not exceed $10^3…10^4$ K/s, and when obtaining tapes or fibers – up to ~ $10^6…10^7$ K/s. This increase in the cooling rate during quenching of the melt by several orders of magnitude reduces the residence time of the melt in the liquid state, thereby virtually eliminating the oxidation of the tape surface [19].

Second, the particle size of the powder obtained by spraying is 20…300 μm, which coincides with the thickness of the amorphous bands. The total surface area of the tape will be ~ 6 times smaller than the total area of the powder particles obtained from the same volume of melt. Under these cooling conditions, both surfaces of the tape will not have time to oxidize, so in the source material (tape) to obtain amorphous powder, the amount of oxides will be very small, and the homogeneity of the amorphous tape thickness (±1…2 μm) contributes to the same cooling rate spilled metal [14].

Wear-resistant coatings of amorphous alloys are used in machine-building enterprises, for example, in the restoration and strengthening of worn surfaces of shafts and gears, in the restoration of crankshafts and camshafts, strengthening of valve heads of vehicles, etc. [18]. In improving the performance of high-load parts and friction units of rolling and pipe rolling equipment, wear-resistant coatings, in particular of amorphous alloys, have not been widely used, except for studies conducted in [20]. Therefore, the problem of using powders of amorphous alloys to strengthen the pipe tool is insufficiently studied, although it has broad prospects for use and significant advantages.

PURPOSE AND OBJECTIVES OF THE RESEARCH

The traditional technology of hardening by thermal and chemical-thermal processing of the press tool from the specified steels has almost exhausted the opportunities for the further increase of its operational properties. Therefore, the aim of this study is to improve the methods of strengthening the main pipe tool – rollers and support bars of cold roller rolling corrosion-resistant pipes, which are difficult to deform, by applying an amorphous coating to increase stability in operation.

MATERIALS AND RESEARCH METHODOLOGY

For the manufacture of heavy-duty pipe tools (rollers and support bars of HPTR mills) most often use secondary hardening semi-heat-resistant steel martensitic class X40CrMoV5-1-1 which is subjected to heat treatment (hardening with tempering). In order to strengthen the tool, it is proposed to perform gas-plasma application of amorphous alloy nanopowders on the basis of the Fe–Si–B system with a thickness of 100…150 μm after hardening with tempering. The chemical composition of steel is shown in Table 1.

Table 1

The chemical composition of steel X40CrMoV5-1-1, % by weight (GOST 5950-73) [3]

C	Si	Mn	Cr	V	Mo	Ni	Cu	S	P
						Not more			
0.32	0.90	0.20	4.50	0.30	1.20	0.35	0.30	0.30	0.03
0.40	1.20	0.50	5.50	0.50	1.50				

A characteristic feature of X40CrMoV5-1-1 steel is complex alloying and tendency to dispersion hardening. The high level of alloying has a positive effect on the strength, hardenability, hardness of steel and makes it possible to use it for tools that experience significant specific pressures and friction during operation. Dispersion hardening provides good deforming properties of the tool [21].

HPTR condition rollers in the amount of three pieces of steel X40CrMoV5-1-1 with a width of 65 mm and a pipe diameter of 16 mm were submitted for testing. The rollers are manufactured by Metinservice Group LLC (Nikopol) and subjected to hardening heat treatment (step hardening from 1070…1080 °C and double tempering at 550…570 °C (1 temper) and 530…550 °C (2 tempering)), and three support laths 210 mm long, 80 mm wide and 47.42 mm high and 25 mm wide tracks (under a pipe with a diameter of 15…22 mm) subjected to hardening heat treatment (step hardening from 1070…1080 °C and double tempering at 550…570 °C (1 tempering), and 530…550 °C (2 tempering)).

Due to the insufficient stability of the rollers (1050…1230 m per set) and support bars (5120…5240 m) of the state of HPTR "15–30", an improved technology for strengthening the rollers and support bars is proposed – after hardening with tempering on the working surfaces of the rollers and support bars performed gas-plasma application of nanocoating of an amorphous alloy based on the Fe–Si–B system to obtain a layer of 0.1…0.15 mm and a hardness of $HV_{0.1}$ 950–1050.

The tape in the amorphous state with a thickness of 15 to 100 μm was obtained by feeding a melt on the surface of a rotating drum-crystallizer at the Institute of Metal Physics of the Academy of Sciences of Ukraine. In this way, the total surface area is reduced (compared to a powder of the same mass), as a result there is almost no oxidation, but the cooling rate due to increased thermal conductivity is much higher, and the same along the entire length of the tape.

The chemical composition of the tape is shown in Table 2.

Table 2

Chemical composition (weight fraction, %) of powder based on Ni and Fe

Element	Ni	Cr	Si	B	C	Fe	Mo	Co	P
Chemical composition	9.49	2.1	1.14	1.09	1.46	other	7.75	7.15	5.63

Annealing and grinding of the tape were performed at the Department of Electrometallurgy of the National Metallurgical Academy of Ukraine. The grinding efficiency of the tape was ensured by low-temperature annealing (180…200 °C) [22], during which the so-called structural relaxation occurs [23, 24], when the amorphous state is preserved, but the tape becomes brittle and easily ground into powder.

Plasma coating of powder coating with a thickness of 100…150 μm on the working surfaces of rings and experimental samples of these steel grades was performed at the UPU-3D laboratory of plasma technologies of the Department of Materials Science and Materials Processing of the Dnieper State Academy of Construction and Architecture.

In a gas-plasma industrial plant (Fig. 6), the spray powder 8 is transported by gas 2, fed perpendicularly to the plasma stream 3 and then through the nozzle 9 to the surface of the tool 11 to be processed. The heated walls of the nozzle 4 with a conical cavity that protects the particles that are sprayed from the oxygen contained in the environment, increase the heating rate of the particles that are sprayed. The compensator 5 at the end of the nozzle 9 eliminates the thermal effects of the plasma flow 3 on the coating 6 and the tool.

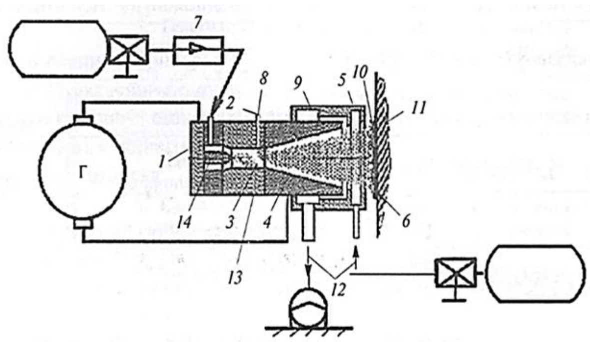


Fig. 6. Scheme of gas-plasma coating of the working surface of the press tool: 1 – plasmatron with ionizing gas; 2 – amorphous powder; 3 – plasma flow; 4 – special nozzle; 5 – compensator of thermal influence of plasma; 6 – finished coating on the working surface of the technological tool; 7 – ionizing gas; 8 – powder; 9 – nozzle; 10 – sprayed layer; 11 – tool; 12 – protective gas; 13 – anode; 14 – cathode

The technology of gas-plasma spraying is as follows: the material applied to the surface of the tool is plasticized by heating, dispersed by a stream of gas and transported to the surface of the tool. When hitting the rough surface of the tool, the particles of molten material are introduced into the surface layer, forming a coating [20].

Quality control of the sprayed coating was performed visually in the presence of flakes and chips. Technological dimensions were controlled using measuring instruments. The microhardness of the samples was measured on a PMT-3 instrument on a prepared coating surface [25]. To study the structural state, the complex of physical and mechanical properties, phase composition, the state of the surface layer of the tool and the samples used the following methods of research and testing:

– metallographic analysis of products and samples using an optical metallographic microscope "Axiovert 200 MAT Zeiss";

– method of electron microscopy using a scanning electron microscope "REM-106I" (accelerating voltage 100 kV) [26].

RESEARCH RESULTS

Modes of thermal hardening of rollers and support laths and prototypes are given in Table 3.

Table 3

Modes of heat treatment of tools and prototypes

Processing mode	Tempering temperature, °C			Hardness $HV_{0.1}$
	I	II	III	
1 – tempering + leave	550…570	530…550	520…530	587…690
2 – X40CrMoV5-1-1 hardening + tempering + coating	550… 570	530… 550	–	950…1050

The technological process of strengthening the pipe tool for the production of corrosion-resistant pipes by applying coatings of amorphous alloy included the following operations:

– smelting of the original billet amorphous alloy of the desired composition;

– obtaining from the procurement of amorphous tape;

– low-temperature annealing of the tape (180…200 °C);

– grinding of a brittle tape after annealing on standard mills;

– standard separation of the obtained powder into fractions;

– direct coating using plasma.

The amorphous alloy billet was smelted in a vacuum induction furnace. Then it was placed in a quartz crucible with a nozzle in its lower part. Subsequently, the workpiece was melted in the inductor field and inert gas was fed into the crucible under pressure, due to which a calibrated flow of melt flowed from the nozzle, which was formed on the rotating surface of the drum into a belt. The realized cooling rate (~ 10^5…10^6 K/s) provided the amorphous state of the tape.

For plasma spraying of the surface of the rings used ground powder with a fraction of 50…150 μm. For the scattering of powders into fractions used metal mesh, woven with square cells of normal accuracy according to GOST 6613-86.

Before use, the powder was dried in an oven at a temperature of 150…200 °C for 2…3 h. The powder was dried on sheets of corrosion-resistant steel, stirring periodically. The thickness of the backfill layer was not more than 20 mm. Drying allows you to remove from the powder adsorbed moisture, which is a source of diffusion hydrogen, which causes increased porosity and the appearance of cracks in the coating [27].

Preliminary surface preparation of the rollers and support strips was to activate the surface and give it the necessary roughness by pneumo-abrasive treatment with electrocorundum brand F-16 at a pressure of 0.5 MPa. It is mandatory and is carried out in order to ensure the required adhesive strength [28].

After pneumatic abrasive treatment of the tool, it was blown with dry compressed air to remove abrasive particles from the surface. The treated surface should be matte, gray, without shiny areas. The interval between pneumatic abrasive treatment and coating should not exceed 2…4 h [29].

The coatings were applied on a universal plasma unit UPU-ZD, designed for the application of wear-resistant, friction, insulating and other special coatings on the surface of parts by plasma spraying of powder materials [30, 31].

Technical characteristics of UPU-3D installation for plasma spraying:

– consumption of plasma-forming gas: argon – 25…30 l/min; nitrogen – 5…10 l/min;

– maximum current – 400 A;

– no-load voltage – 160 V;

– the fraction of the sprayed powder – 40….315 μm;

– productivity of spraying – to 2 kg/h;

– service life of the nozzle on technical nitrogen – up to 140 h;

– water consumption for cooling the plasmatron – up to 7 l/min;

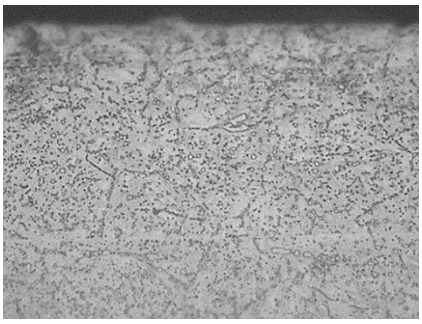
– water pressure at the entrance to the plasmatron – not less than 0.2 MPa;

– water temperature at the exit of the plasmatron – not more than 50 °C;

– efficiency of installation – 60%;

– noise level when working on nitrogen – 80 dB.

Microstructures of steel samples (optical and electronic studies) are shown in Figs. 7 and 8.



a

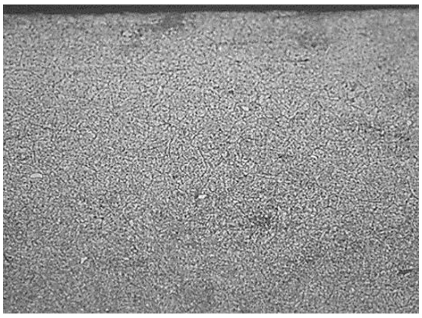


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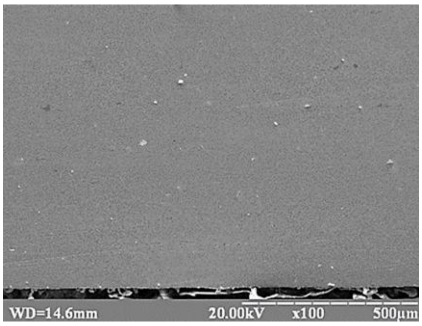
*Fig. 7. Microstructure of the surface of steel X40CrMoV5-1-1 samples after plasma coating (optical studies): a – *200; b – *800*



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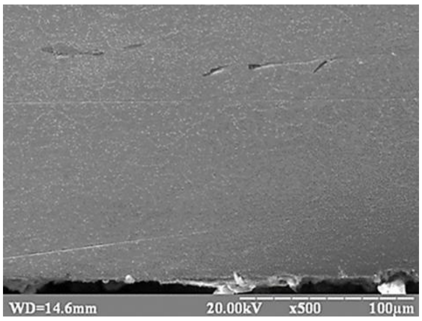

b

*Fig. 8. Microstructure of the surface of steel X40CrMoV5-1-1 samples after plasma coating (electronic study): a – *100; b – *500*

On the surface of the samples – a coating of amorphous alloy, and the core and the transition layer – martensite released and carbides of chromium, tungsten, molybdenum, vanadium.

Tests of rollers and support bars were carried out on the condition of HPTR "15–30" "OS VO OSCAR" (Nikopol), which showed an increase in their mechanical properties. The test results showed that the rollers and support bars, additionally subjected to gas-plasma coating of amorphous alloy based on the Fe–Si–B system showed a resistance of 1860…2030 m per set and 5860…5930 m, respectively, due to higher hardness (increased hardness in 1.65–1.8 times and 1.2–1.3 times, respectively), strength, durability.

CONCLUSIONS

The analysis of literature data on means of increase of wear resistance and hardness of a surface of the tool, in particular pipe-rolling is carried out.

The rollers and support bars of the state HPTR "15–30" made of steel X40CrMoV5-1-1, which were coated with amorphous alloys, were investigated. The technology is proposed, which includes obtaining an amorphous tape of the Fe–Si–B system, powder from it and applying it to the surface of the pipe rolling tool.

Factory testing of coated rollers and support bars showed an increase in their stability by 20…25% compared to the technology used in enterprises and improving the quality of the inner surface of the pipes.

The proposed technology of heat hardening and additional application by plasma spraying on the working surface of the pipe tool nanocoatings of amorphous alloys with a thickness of 100…150 μm eliminates the third temper, changes the structure and properties of the surface layer, increases strength, wear resistance and hardness to $HV_{0.1}$ 950–1050 (HV 587–690 on existing technology). As a result, the teel acquires a high hardness on the surface, which is required under conditions of significant pressure and friction when working on tube rolling mills.

REFERENCES

1. V.R. Kargin, B.V. Kargin. *Theory and technology of pressing, rolling and drawing*: Textbook. way. Samara: Izd-vo SSAU, 2014, 72 p.

2. *Technologies for the production of stainless steel pipes:* A collection of lectures / For about. ed. E.Ya. Lezinskaya; composition. K.M. Bildin. Nikopol: "Centravis", 2019, 89 p.

3. Yu.B. Chechulin. *Cold rolling of pipes*: Textbook. way. M.: "Metallurgy", 2017, 332 p.

4. G.A. Orlov. *Cold rolling and drawing of pipes*: Textbook. way. Ekaterinburg: "UrFU", 2011, 188 p.

5. N.A. Tselikov, A.V. Chekulaev. Cold rolling mills of VNIIMETMASH construction pipes // *Heavy engineering*. 2010, N 5, p. 28-31.

6. Cold rolling mills: US Pat. 2397033 RF: NS Penkov et al.: application 12.08.2009, publ.20.08.2010, Bull. N 23, 4 p.

7. V.T. Vyshinsky. Directions and tasks of improvement of mills of cold rolling of pipes by rollers // *Bulletin of SevNTU*: Coll. Science. pr., Sevastopol, 2011, N 120, p. 268-271.

8. V.A. Verdenevsky. *Roller mills of cold rolling of pipes*: Textbook. M.: "Metallurgy", 1992, 240 p.

9. V.I. Bolshakov. *Equipment of thermal shops, technologies of heat treatment of metal products*: Textbook. Dnepropetrovsk: "Dnepr-VAL", 2010, 378 p.

10. M. Bader, H.-J. Spies, K. Hock, E. Broszeit, H.-J. Schroder. Properties of duplex treated (gas-nitriding and PVD-TiN, Cr2N) low alloy steel // *Surface and Coatings Tecnollogy*. 1998, v. 98, p. 891-896.

11. T. Bell, H. Dong, and Y. Sun. Realising of the potential of duplex surface engineering // *Tribology International.* 1998, v. 31, N 1-3, p. 127-137.

12. Andre Anders. *Handbook of plasma immersion ion implantation and deposition*. John Wiley & Sons, inc, 2000.

13. I.S. Geltman, E.M. Rabinovich. Powder materials for gas thermal coating // *Steel.* 1985, N 4, p. 78-81.

14. V.E. Panin, V.P. Sergeev, A.V. Panin. Nano-structuring of surface layers, application of nanostructured coatings – an effective way to strengthen modern structural and tool materials // *Physics of Metals and Metallurgy*. 2007, v. 104, N 6, p. 650-660.

15. K. Suzuki, H. Fujimori. *Amorphous alloys* / Ed. Masumoto C.: Per. with Japanese. M.: “Metallurgy”. 1987, 328 p.

16. G.A. Srebryansky, Yu.N. Starodubtsev. Basic principles of improving the technology of production of amorphous tape // *Steel.* 1991, N 9, p. 73-78.

17. M.V. Selivanov, N.M. Davydova. Micro-crystalline alloys abroad // *Ferrous metallurgy*. 1988, N 1, p. 27-43.

18. G.A. Srebryansky, A.P. Stovpchenko. A new approach to obtaining powder materials // *Materialy V Miedzynarodowa Sasja Naukowa “New Technologie i osiagniecia w metallurgii inzynierii materialowej”* (Poland), Politechnica Czestochowska, Widawnictwo Wipmifs, 2004, p. 618-621.

19. S.R. Rakhmanov, G.A. Srebryansky, A.N. Golovachev, A.T. Mammadov, N.V. Oros. Increase in wear resistance of the press tool by means of coverings from amorphous alloys // *Vestnik mechanical engineering*. 2018, N 1, p. 55-60.

20. Problem of the synergetic, deformation, wear, and entropy of metallic materials polyanov, metal science and heat treatment, vol. 36, issue 3-4, pp. 148-152. DOI: 10.1007 / BF01398846 publ. MAR- APR 1994; document type: Article.

21. *Ultrafast hardening of liquid alloys*: Sat. scientific Trudov. Under the editorship of Herman G.: Per. with English Zhurakhovsky E.A., Fedorova V.V. / Ed. Borisova V.T. M.: “Metallurgy”, 1986, 375 p.

22. I.B. Kekalo. *Atomic structure of amorphous alloys and its evolution*: Textbook. way. M.: Izd. “Study” MISiS, 2006, 340 p.

23. A.s. USSR № 1535064. *Plasma spraying method* / Kalita V.I., Kudinov V.V., Vernikovsky B.K., Kopteva O.G., 1990.

23. V.V. Kudinov, V.I. Kalita, O.G. Kopteva. Investigation of the process of formation of macro- and microstructure of particles of gas-thermal coatings. *Fizhom*. 1992, N 3, p. 88-92.

24. A.A. Ivlev, L.A. Gorbatenko, V.I. Kalita, V.V. Kudinov, B.K. Vernikovsky. Form and structure of fast-hardened nickel-based powders // *Powder Metallurgy*. 1990, N 8, p. 1-5.

25. N.N. Savvateev, K.V. Pocholok, Kudinov, V.I. Kalita, O.G. Kopteva. Investigation of amorphous Fe80B20 coatings by the NGR method // *International Symposiumon muclear-spectroscopycal investiga tions of hyperfine interctions,* USSR, Uzgorod, 1991, p. 172.

26. V.I. Kalita, I.B. Kekalo, D.I. Komlev, V.E. Taranichev. Structure and properties of massive amorphous magnetic soft coatings obtained by plasma sputtering // *FMM*. 1995, v. 80, issue 2, p. 35-48.

27. V.N. Timofeev, V.I. Kalita, D.I. Komlev. Formation of coatings with amorphous structure by plasma spraying // *FHOM*, 1996, N 4, p. 47-49.

28. V.I. Kalita, D.I. Komlev. Peculiarities of the formation of the structure of amorphous-crystalline coatings during plasma sputtering // *FHOM*, 1996, N 4, p. 43-46.

29. E.V. Korbut. Modern Methods of Surface Hardening of Tools // *Problems of Grating and Construction*. 2010, VIP. 54, p. 149-153.

30. L.G. Voroshnin. Prospects for the development of chemical-thermal treatment // *Strengthening technologies and coatings.* 2008, N 1(37), p. 5-8.

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УПРОЧНЕНИЕ ТРУБНОГО ИНСТРУМЕНТА ДЛЯ ХОЛОДНОЙ РОЛИКОВОЙ ПРОКАТКИ КОРРОЗИОННО-СТОЙКИХ ТРУБ НАНЕСЕНИЕМ ПОКРЫТИЙ АМОРФНЫХ СПЛАВОВ

Л.С. Кривчик, Т.С. Хохлова, В.Л. Пинчук, А.Н. Головачев, Г.А. Сребрянский, В.К. Носенко, О.Б. Загородний

При производстве труб из коррозионно-стойких сталей на трубопрокатных установках актуальной проблемой является низкая устойчивость трубного инструмента. Поэтому создание высокопроизводительных и устойчивых в эксплуатации инструментов связано в первую очередь с получением и обработкой таких материалов, которые могли бы противостоять жестким условиям работы. В работе предложена технология термоупрочнения трубного инструмента для холодной роликовой прокатки коррозионно-стойких труб (роликов и опорных планок станов ХПТР) из стали 4Х5МФ1С, которая исключает третий отпуск и использует нанесения покрытия из порошков аморфных сплавов толщиной 100…150 мкм. Вследствие предложенной технологии повышаются прочность, износостойкость, а также твердость до $HV_{0,1}$ 950–1050 (по сравнению с HV 587-690 по существующей технологии термической обработки в заводских условиях). Проведен широкий комплекс исследований структуры покрытия и промышленных испытаний роликов и опорных планок. Показано, что газоплазменное нанесение покрытий из аморфного сплава на основе системы Fe–Si–B увеличивает твердость поверхности инструмента в 1,3–1,6 раза и их устойчивость на ~ 30…50%.

ЗМІЦНЕННЯ ТРУБНОГО ІНСТРУМЕНТУ ДЛЯ ХОЛОДНОЇ РОЛИКОВОЇ ПРОКАТКИ КОРОЗІЙНО-СТІЙКИХ ТРУБ НАНЕСЕННЯМ ПОКРИТЬ АМОРФНИХ СПЛАВІВ

Л.С. Кривчик, Т.С. Хохлова, В.Л. Пінчук, А.М. Головачов, Г.О. Сребрянський, В.К. Носенко, О.Б. Загородній

При виробництві труб із корозійно-стійких сталей на трубопрокатних установках актуальною проблемою є низька стійкість трубного інструменту. Тому, створення високопродуктивних і стійких в експлуатації інструментів зв'язане у першу чергу з одержанням й обробкою таких матеріалів, які могли б протистояти жорстким умовам роботи. В роботі запропонована технологія термозміцнення трубного інструмента для холодної роликової прокатки корозійно-стійких труб (роликів і опорних планок станів ХПТР) зі сталі 4Х5МФ1С, яка виключає третій відпуск і використовує нанесення покриття із порошків аморфних сплавів товщиною 100…150 мкм. Внаслідок запропонованої технології підвищуються міцність, зносостійкість, а також твердість до $HV_{0,1}$ 950–1050 (в порівнянні із HV 587–690 за існуючою технологією термічної обробки в заводських умовах). Проведено широкий комплекс досліджень структури покриття і промислових випробувань роликів і опорних планок. Показано, що газоплазмове нанесення покрить з аморфного сплаву на основі системи Fe–Si–B збільшує твердість поверхні інструменту в 1,3–1,6 рази і їх стійкість на ~ 30…50%.