Andrii A. Holiakevich, Leonid N. Orlov

Surfacing Performed Using Flux-Cored Wires in Ukrainian Companies

Abstract: The article describes the experience of extending the service life of various machinery parts by surfacing them with flux-cored wires. High wear resistance during the rolling and straightening of steel is achieved by the formation of a martensitic matrix reinforced with dispersive carbides.

Keywords: flux-cored wires, surfacing, extending service life of industrial machinery

DOI: *10.17729/ebis.2016.5/13*

The economical and efficient use of resources provides the sustainable development of the national economy. In Ukraine, many companies are increasingly interested in using energy, material resources and labour in a more economical way. An efficient and relatively uncomplicated technological process partly allowing the satisfaction of the above-presented objectives is arc surfacing. The extension of the service life of machinery used in various industries is obtained by making the work surfaces of parts resistant to wear, thus prolonging their service life and preventing costs connected with the replacement of parts. Surfacing, involving the use of flux-cored wires, has proved to be highly effective when repairing metallurgical machines, their critical parts and technological tools (metallurgical rollers, furnace rollers, straightener rollers, rollers used in the semi-product continuous casting lines, metal cutters etc.) exposed to impacts, complex stress-strain states or friction. All these destructive factors require that hardening layers be provided with special properties.

Surfacing of Rolling Mill Rollers

Maintenance services of Ukrainian and Russian metallurgical complexes usually perform surfacing using the PP-NP-35W9H3SF flux-cored wire when repairing rollers of roughing and shape mills used for the rolling of slabs or ingots. During operation, work surfaces of rollers are subjected to band-like wear, cracking and metal spalling. To a significant extent, this wear of roller work surface is connected with the structure of metal and the morphology of its structural constituents [1, 2].

Grade 35W9H3SF belongs to heat-resistant metals. According to publications [3-5], the solidification of this metal is divided into 3 stages of structural formation, with a particular role played by the peritectic transformation. The structure of the weld deposit depends primarily on the content of carbon, additional alloying elements and mixtures as well as the amount and morphology of retained austenite. The existing methods investigating cyclical thermal loads and wear at high temperatures are not able to

Andrii A. Holiakevich, Leonid N. Orlov – OOO "TM Weltek", Kiev, Ukraine

precisely identify wear resistance in rolling conditions. Operational tests were assumed to most conveniently address the above named issue. The operational tests described in the article were performed in the following metallurgical complexes in Ukraine: The Ilyich Metallurgical Complex in Mariupol, Azovstal in Mariupol, and Kryvorizhstal in Krywyj Rih. Before the tests, metallurgical rollers were surfaced using the PP-NP-35W9H3SF (C-Si-Mn-W-Cr-V) and Veltek-N505 (C-Si-Mn-W-Cr-Mo-Ni-V) flux-cored wires. The purpose of verifying the selected types of the alloy systems of surfaced layers was to assess the effect of retained austenite and its morphology on roller surface wear.

The structure of the weld deposit surfaced using the PP-NP-35W9H3SF flux-cored wire contained coarse-acicular martensite with islands of retained austenite and extended interlayers of carbide eutectics on the boundaries of primary austenite grains (Fig. 1a). The grains and their boundaries contained chromium and tungsten carbides as well as dispersive vanadium carbides. The structure of the weld deposit surfaced using the Veltek-N505 flux-cored wire contained fine-acicular martensite surrounded by retained austenite on the boundaries of primary grains. The grains contained chromium, tungsten, molybdenum and vanadium carbides (Fig. 1b). The surfaces of the rollers were free from annealing cracks.

The averaged indicators of relative wear resistance, determined on the basis of the condition of the surface as regards its usability for further operation were identified taking into consideration wear, the relative crack resistance and the number of cracks as well as the divergence and the depth of cracks on the work surface of rollers (Table 1).

Traditionally, the rollers of the first and second stand of the rolling mill being part of the TPA «30–102» unit of ZAO "NIKOTUBE" (Nikokol Seamless Tubes Production Plant) were surfaced using the PP-NP-35W9H3SF flux-cored wire. The hardness of the surfaced layer amounted to 46÷48 HRC. The temperature of semi-finished tubes fed to the rolling mill stand amounted to 1200÷1250°C. Because of elastic-plastic strains, the rolling of semi-finished tubes led to the change of the roller pass

Table 1. Wear indicators of the work surface of rollers subjected to surfacing

Wire grade	Alloy system	Hardness, HRC	Relative wear resistance	Relative crack resistance
PP-Np-35W9H3SF	C-Si-Mn-Cr-W-V	46-48	1.0	1.0
Veltek-N505RM	C-Si-Mn-Cr-W-Mo-V-Ni	50-54	1.3	2.0

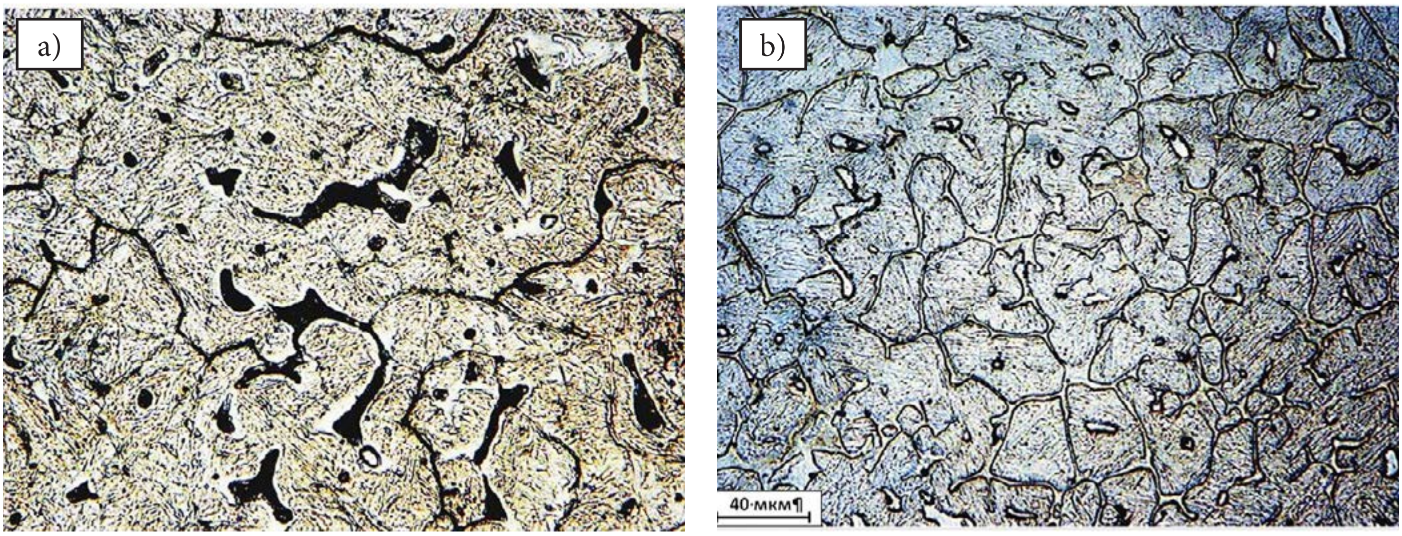

Fig. 1. Microstructure of metal surfaced using the wire: a – PP-Np-35W9H3SF, b – Veltek-N505RM; mag. 500x

work surface. After rolling 1000÷1200 tons of semi-finished products, the wear of rollers at the bottom of the calibre amounted to 3÷5 mm, and the roller pass surface contained annealing cracks, scratches as well as longitudinal and transverse cracks deteriorating the quality of tubes. The presence of deep scratches on the roller pass surface led to the formation of imperfections rolled on the surface of tubes; such defects are very difficult to detect visually directly after rolling and are usually identified at the final stages of production, e.g. when performing non-destructive tests.

The increase in wear resistance was obtained by using the Veltek-N480NT (C-Si-Mn-Cr-V-Mo-W) flux-cored wire. The structure of the metal subjected to surfacing was composed of fine-acicular ferrite with retained austenite on grain boundaries and fine precipitates in grains

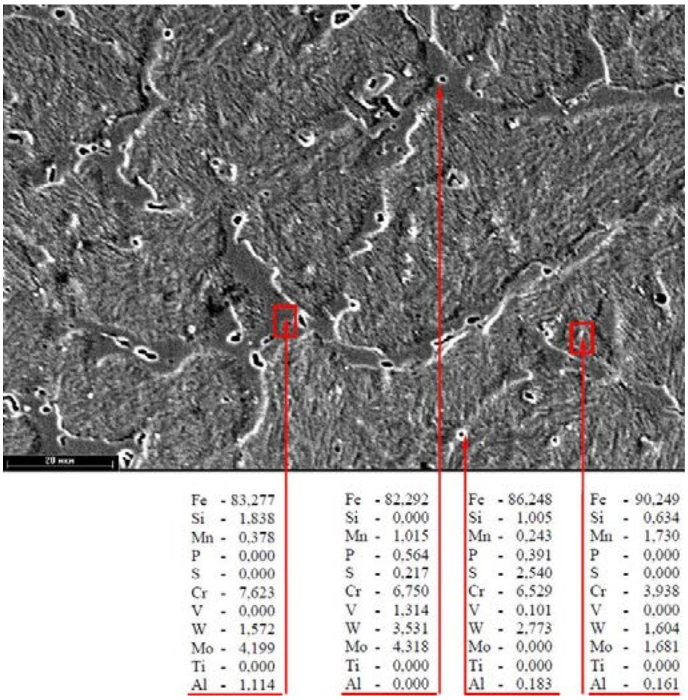

Fig. 2. Microstructure and the chemical composition of metal surfaced using the Veltek-N480NT wire

(Fig. 2). The presence of carbide precipitates on grain boundaries was insignificant. Dispersive carbides are uniformly arranged in grains and on their boundaries. The hardness of the surfaced layer amounted to 50÷56 HRC. The rollers of the first stand were removed after the rolling of 5000 tons of tubes. The wear at the bottom of the calibre amounted to 0.3÷0.5 mm. The condition of the roller surface was satisfactory; the surface was smooth and free from cracks. The wear of the rollers of the second stand amounted to 1.5÷2.0 mm after the rolling of 8790 tons of tubes. The service life of the rollers increased from 1200 to 8000 tons of rolled tubes.

Surfacing of Continuous Steel Casting Line Rollers

The inter-overhaul service cycle of continuous steel casting machinery depends on the wear resistance of the work surface of supporting, pressing and drawing rollers subjected to high-temperature and forceful cyclical effect of primary technological tools in an aggressive environment [6, 9]. The extension of the service life of these rollers is solved in a complex manner, i.e. by selecting high-temperature creep resistant roller material, optimising the alloy system of metal subjected to surfacing and using a surfacing technology taking into consideration the conditions of initial heat treatment. Factors determining the service life of rollers include the chemical composition and the structure of a work layer subjected to surfacing [7, 8, 10]. Rollers are made of creep resisting steels 15H1MFJu, 25H1M1F, 40H1MFA, 16CrMo4, 21CrMoV5-11 and 25CrMo4. The global trends as regards the surfacing of the

Table 2. Chemical composition of weld deposit (% by weight) and hardness

Wire	C	Si	Mn	Cr	Ni	Mo	V	Nb	N	HRC
Chromecore 414N-O	0.04	0.7	1.2	12.7	4.0	0.4	-	-	0.12	40-46
SK 742 N-SK	0.04	0.4	1.3	13.5	3.3	1.3	0.10	0.08	0.06	42-45
OK Tubrodur 15.73S	0.15	0.3	1.2	13.0	2.5	1.5	0.25	0.25		45-51
Weltek-N470	0.10	0.5	1.3	13.5	2.5	1.2	0.15	0.1	0.06	40-44
Weltek-N470G	0.15	0.5	1.3	13.5	2.5	1.2	0.15	0.1	0.06	44-48

work layer of continuous steel casting rollers are predominantly limited to the use of two alloy systems, i.e. 1 – (Cr-Mn-Ni-Mo-N) and 2 – (C-Cr-Mn-Ni-Mo-V-Nb) (see Table 2). The difference between these two systems is the following: system 1 is resistant to annealing crack formation, whereas system 2 is resistant to abrasive wear, particularly on the rectilinear section of the line for continuous steel casting.

When manufacturing and repairing rollers, the Ilyich MMK, Azovstal (Mariupol) and NKMZ (Kramatorsk) industrial complexes use submerged arc surfacing and Veltek-N470 flux-cored wire (ϕ 3.0÷3.6 mm) under the AN-20 or AN-26 flux, moving the single wire in a helical manner, with and without transverse movements. The Old Kramatorsk Machine Building Factory in Kramatorsk performed the 82% Ar+18%CO_2–shielded MAG surfacing of continuous steel casting rollers using the Veltek-N470G flux-cored wire (ϕ2.0 mm). After finishing, the hardness of the surfaced layer amounted to 44÷48 HRC and satisfied the customer's requirements. The structure of the surfaced metal was composed of low-carbon fine-acicular martensite reinforced with dispersive carbides and nitrides. The content of ferrite δ did not exceed 5%. The production and repair surfacing provided the service life of the rollers of the curvilinear section of the continuous steel casting machine amounting to 3000 heats and of the rectilinear section amounting to 7500 heats; each section weighed 175 tons.

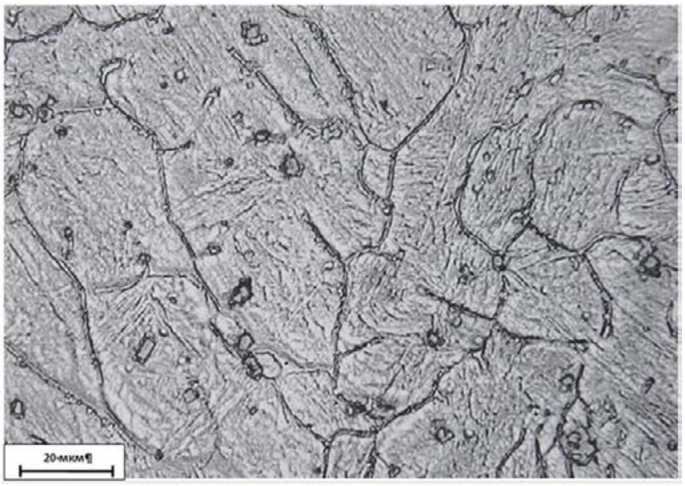

Fig. 3. Microstructure of the metal surfaced using the Veltek-N470 wire, volumetric content of δ 5.2%; hardness after surfacing 42÷46 HRC; mag. 1000x

Surfacing of Crane Wheels

Companies of many industries operate a significant number of cranes, entailing significant costs related to crane wheel repairs, particularly in terms of cranes used in metallurgical departments. The analysis of the reasons for the wear of the rolling surface of crane wheels surfaced using traditional filler metals, i.e. Np-30HGSA and PP-NP-18H1G1M, enabled the identification of requirements related to the structure of surfaced metal ensuring increased wear resistance. A significant increase in the wear resistance of repaired parts can be achieved using filler metals ensuring the obtainment of surfaced metal having the structure of metastable austenite, undergoing martensitic transformation triggered by load-related strain during operation [11-14].

According to customer requirements, the hardness of surfaced layers of wheels should not exceed 40 HRC, taking into consideration the necessity of preventing the premature wear of the crane track. The wheel wear analysis performed after the service life revealed that areas particularly susceptible to wear were wheel flanges. In the Ilyich MMK industrial complex, it was proposed that wheels particularly affected by loads be surfaced using submerged arc and the Veltek-N285.01 filler metal wire with the C-Cr-Mn-Mo-V alloy system. The surfaced layer developed the structure of metastable austenite strongly hardening if exposed to strain (Fig. 4).

The stress-relief tempering performed at 600°C was followed by the formation of dispersive chromium, vanadium and molybdenum carbide precipitates. The depletion of matrix grains in carbon and alloying elements intensified strain martensitic transformation, thus leading to a significant growth in the wear resistance of the wheel rolling surface metal subjected to surfacing. According to the

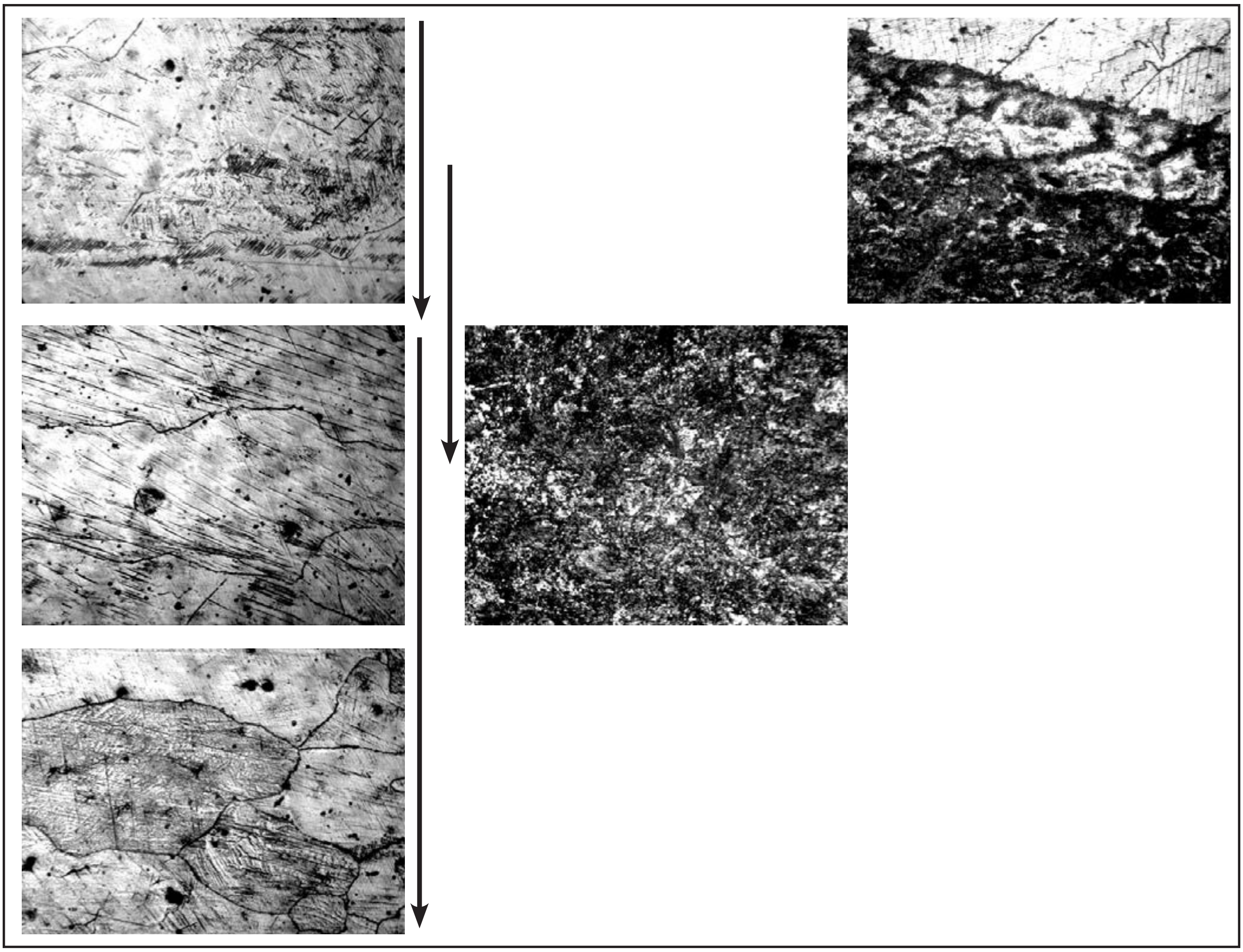

Fig. 4. Microstructures of layers surfaced using the Veltek-N285.01 flux-cored wire (from the surface to the base material). Mag. 550x

X-ray-based structural analysis performed after annealing, the volumetric content of martensite present on the surfaced wheel surface increased 1.0÷2.0 times and constituted 30÷35% of the volume. The hardness of the layer after surfacing amounted to 217÷220 HB, and after hardening to 380÷410 HB.

The laboratory test results concerning the block-roller type sliding friction and abrasion, the highest wear resistance was obtained when surfacing was performed using the Veltek-N285.01 wire (Table 2). The following variants of the technology were used:

1. surfacing of wheel flanges and rolling surface using the Veltek-N285.01 wire,
2. surfacing of the rolling surface using the Veltek-N300 (30HGSA) or Veltek-N350 (18H1G1M) wire and surfacing of wheel flanges using the Veltek-N285.01 wire.

The service life of crane wheels was extended 3÷5 times, which significantly reduced crane service-related costs. Surfacing performed using the Veltek-N285.01(PP-Np-14Cr12Mn 12MV) flux-cored wire can also be recommended when repairing a company's internal rolling stock wheels, industrial cars used in open pits, various rollers, pins of steel pouring ladles, and parts quickly wearing in poorly corrosive environments, e.g. hydraulic press plungers, cut-off valves etc.

Surfacing of Straightener Rollers

Straightener rollers are usually made of little technologically advanced tool steel 9H1 subjected to surface heat treatment using high frequency or industrial frequency current. Harsh operating conditions of these rollers, particularly when straightening sheets/plates and rolled

Table 3. Relative wear resistance of metal surfaced using the PP-Np-18H1G1M, Np-12H13, Np-12H18Ni10T, Np-30Cr10Mn10Ti and Veltek-N285.01 wires

No.	Flux-cored wire	Heat treatment conditions	Relative wear resistance*	Relative resistance in dry abrasion conditions*
1	PP-Np-18H1G1M (standard)	Surfacing + annealing 550°C (1 h)	1.0	1.0
2	Np-12H13	Surfacing + annealing 550°C (1 h)	1.2	1.3
3	Np-12H18N10T	Surfacing + annealing 550°C (1 h)	0.6	0.7
4	Veltek-N285.01	Surfacing + annealing 600°C (1 h)	2.3	3.2
5	Np-30Cr10Mn10Ti	Surfacing + annealing 550°C (1 h)	2.0	3.0

* Determined as the ratio between the mass depletion of standard surfaced metal and the mass depletion of properly surfaced metal

sections made of alloy steels with scale, lead to their premature wear. The inadequate service life of straightener rollers made of steel 9H1 subjected to surface hardening, though characterised by relatively high hardness (61÷63 HRC), can be ascribed to the insufficient number of hardening phases (carbides, carbonitrides) in the metal structure of these rollers and to the inadequate thickness of the hardened layer (between 1.5 and 5 mm). Until recently, straightener rollers made of steel 9H1 were not subjected to repair surfacing due to the unsatisfactory weldability of this steel grade.

The effective technological solution was proposed by OOO «Vosstanovlenie», Lipetsk and OOO «TM WELTEK», Kiev, Ukraine. Repairs and production of such rollers should involve the use of high-chromium medium-carbon surfacing filler metals on the basis of volumetrically heat processed steel 40H with the surface layer surfaced using WT550.01-F (C-W-Mo-Cr-V) and WT545-F (C-Mo-Cr-V-Ni) flux-cored wires, where the hardness of the surfaced layer amounts to 57-60 HRC. The high wear resistance and hardness of the work surface of rollers is obtained through the formation of the dispersive carbide-reinforced martensitic structure and the reduction of the grain size of the primary structure when performing surfacing using a wire having a diameter of 2.0 mm and parameters optimally combining efficiency and heat input (Fig. 5). Surfacing was performed using positive polarity DC under the AN-26 flux, current of 260÷280 A, arc voltage of 30 V and a welding rate of 28÷30 m/h.

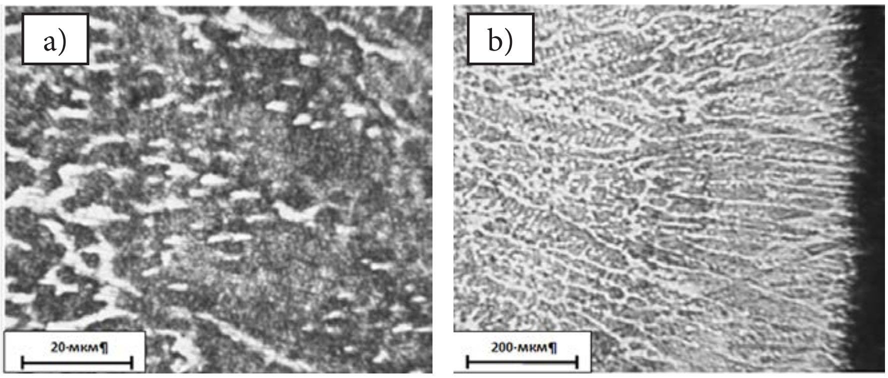

Fig. 5. Microstructure of the roller work surface metal surfaced using the Veltek-N545 flux-cored wire: a – mag. 1000x, b – mag. 100x

Rollers of sheet straighteners having barrel diameters of 190, 230, 250 and 360 mm (made of steel 9H1) repaired using the new technology enabled the OAO «Vyksunskiy Metallurgicheskiy Zavod» industrial complex to extend the service life of the rollers up to 3 to 4 times in comparison with new surface hardened rollers made of steel 9H1. In addition, the cost of repair of the rollers refurbished using the new technology was half the cost of purchasing new rollers made of steel 9H1.

Surfacing of Power Hydraulics Elements

Another crucial task is the overhaul and production of new mining equipment as well as the repair and replacement of hydraulic elements. During operation, the work surfaces of prop equipment are exposed to impact and abrasive loads exerted by rocks and coal. In addition to wear and impact-induced indents, the work surfaces of piston rods and plungers undergo pitting and intercrystalline corrosion as well as are exposed to the settlement of exchange reaction products caused by the contact with underground water, causing damage sealing elements and rendering hydraulic equipment useless. Therefore, it is necessary to increase the reliability and wear resistance of the powered support prop elements by making wear resistant layers on the work surfaces of piston rods plungers. It should be noted that the hardness of a hardened surface ought to exceed 40 HRC. The corrosion of piston rods and plungers is usually present in the heat affected zone (HAZ) of the previous run.

Tests concerning the effect of surfaced metal chemical composition on the development of corrosion were performed in conjunction the Karpenko Physico-Mechanical Institute of the NAS of Ukraine, Lviv, Ukraine [15, 16]. Corrosion was caused by the formation of chromium carbides ($Cr_{23}C_6$) on metal grain boundaries in the HAZ. The additional use of alloying components enabled the obtainment of a surfaced layer having the structure of precipitation hardened martensitic steel with intercrystalline phases formed during welding and heat treatment; these phases additionally harden the metal and significantly reduce the probable formation of chromium carbides ($Cr_{23}C_6$) on grain boundaries (Fig. 6).

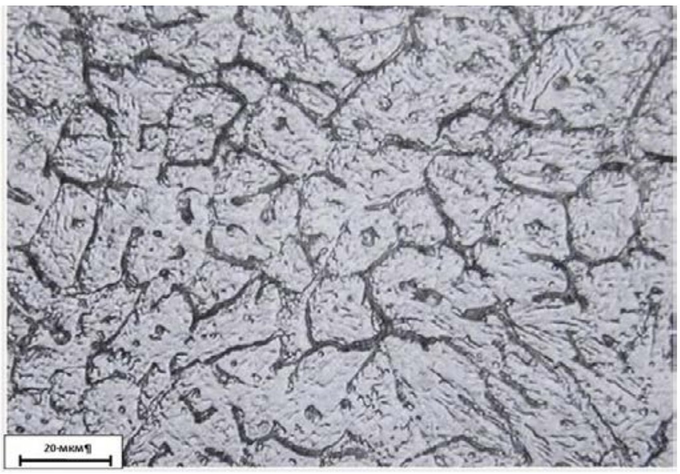

Fig. 6. Microstructure of the hardening layer metal subjected to surfacing using the Veltek-N425 wire; mag. 1000x

The tests results enabled the optimisation of the C-Mn-Si-Cr-Ni-Mo-V alloy composition of the Veltek-N425, Veltek-N425.01 and Veltek-N425.02 flux-cored wires, varying as regards the corrosion resistance of the surfaced metal in variously aggressive underground waters. The developed technology involved two-layer surfacing using the Veltek-N425 wire (ϕ 2.0 mm) under the AN-26p flux (Fig. 7). The thickness of the surfaced layer amounted to 3.0÷3.5 mm. The surfacing of piston rods and plungers of powered supports was used successfully at the «NPP Specuglemash» Company, Gorlovka, Ukraine as well as when surfacing cut-off equipment fixtures in Ukrainian and Russian companies.

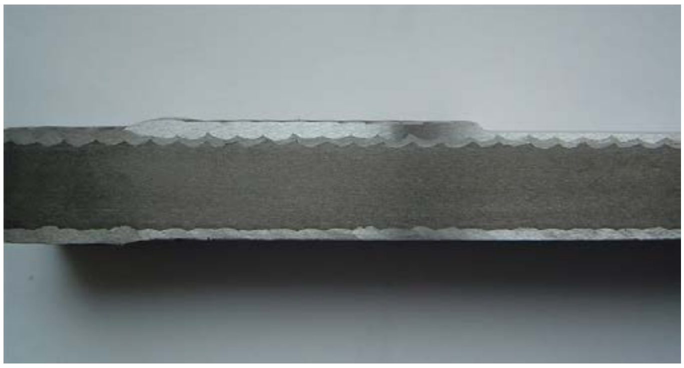

Fig. 7. Macrostructure of the surfaced plunger fragment

Summary

In production conditions it is possible to effectively use the repair surfacing of critical machinery parts using flux-cored wires. Increasing the wear resistance of work surfaces extends the period of safe operation of machinery and reduces service and repair costs.

References

[1] Кондратьев И. А., Васильев В. Г., Дзыкович И. Я.: *Исследование структурной неоднородности наплавленного металла типа 35В9Х3СФ и ее влияние на работоспособность наплавленных прокатных*

валков. Автоматическая сварка. 1996. № 6. pp. 17–20
[2] Кальянов В. Н.: *Структура и характеристики износостойкого экономнолегированного наплавленного металла*. Сварочное производство. 1997. № 4. pp. 13–17
[3] Гольдштейн М. И., Грачев С. В., Векслер Ю. Г.: *Специальные стали*. М.: Металлургия, 1985. p. 408
[4] Геллер Ю. А.: *Инструментальные стали*. 5-е изд. М.: Металлургия, 1983. p. 527
[5] Калинушкин Е. П., Кунгуров В. М., Коваленко В. В.: Структурообразование при затвердевании теплостойких сталей. Изв. ВУЗов. Черная металлургия. 1992. № 1. pp. 88–92
[6] Якушин Б. Ф., Цирко П. А.: *Особенности технологии дуговой наплавки роликов для установок непрерывной разливки сталей*. Сварка и диагностика. 2009. № 5. pp. 35–40
[7] Опарин Л. И., Малкин А. Л., Гладкий П. В. и др.: *Наплавка роликов слябовых машин непрерывного литья заготовок*. Автоматическая сварка. 1991. № 4. pp. 63-66
[8] Носоченко О. В., Матюхин А. В.: *Повышение стойкости МНЛЗ и улучшение качества слитков*. Сталь. 1986. № 7. pp. 34–36
[9] Домбровский Ф. С., Лещинский Л. К.: *Работоспособность наплавленных роликов машин непрерывного литья заготовок*. К.: ИЭС им. Е. О. Патона НАН Украины, 1995. p. 197
[10] Коротков В. А., Михайлов И. Д., Веселов А. С. и др.: *Наплавка роликов МЛНЗ*. Сталь. 2003. № 8. pp. 60-63
[11] Разиков М. И., Ильин В. П.: *Сварка и наплавка кавитационной стали марки 30Х10Г10*. М.: НИИМАШ, 1964. p. 35
[12] Богачев И. Н., Минц Р. И.: *Повышение кавитационно-эрозионной стойкости деталей машин*. М.: Машиностроение, 1964. p. 142
[13] Малинов Л. С., Чейлях А. П., Харланова Е. Я. и др.: *Выбор состава хромомарганцевой стали с метастабильным аустенитом в качестве основы наплавочного материала*. Известия ВУЗ. Черная металлургия. 1994. № 8. pp. 45–46
[14] Малинов Л. С., Малинов В. Л.: *Марганецсодержащие наплавочные материалы*. Сварочное производство. 2001. № 8. pp. 34–36
[15] Голякевич А. А., Орлов Л. М., Похмурська Г. В. та ін.: *Корозійні характеристики наплавлених шарів для штоків гідроциліндрів гірнодобувного обладнання*. Хімічна механіка матеріалів. Проблеми корозії та протикорозійного захисту матеріалів. Львів, 2014. Спец. випуск № 10. pp. 651–656
[16] Holyakevych A. A., Orlov L. M., Pokhmurska H. V. et al.: *Influence of the Phase Composition of the Layers Deposited on the Rods of Hydraulic Cylinders on Their Local Corrosion*. Materials Science. 2015. Vol. 50. Issue 5. pp. 740–747