



Improving the quality of layers deposited on rolling rolls by optimising the composition of flux-cored wires

N. A. Kozyrev, N. V. Kibko, A. A. Umanskii, D. A. Titov & P. D. Sokolov

To cite this article: N. A. Kozyrev, N. V. Kibko, A. A. Umanskii, D. A. Titov & P. D. Sokolov (2018) Improving the quality of layers deposited on rolling rolls by optimising the composition of flux-cored wires, *Welding International*, 32:11, 724-728, DOI: [10.1080/09507116.2018.1443884](https://doi.org/10.1080/09507116.2018.1443884)

To link to this article: <https://doi.org/10.1080/09507116.2018.1443884>



Published online: 26 Dec 2019.



Submit your article to this journal [↗](#)



Article views: 3



View related articles [↗](#)



View Crossmark data [↗](#)

ARTICLE



Improving the quality of layers deposited on rolling rolls by optimising the composition of flux-cored wires

N. A. Kozyrev^a, N. V. Kibko^a, A. A. Umanskii^a, D. A. Titov^a and P. D. Sokolov^b

^aSiberian State Industrial University, Novokuznetsk, Russia; ^bElSib Company, Novosibirsk, Russia

ABSTRACT

Experiments were carried out to investigate the effect of adding carbon–fluorine compounds (the waste from metallurgical production) and nickel powder to the composition of flux-cored wires of the C–Si–Mn–Cr–W–V and C–Si–Mn–Cr–V–Mo alloying systems. The results show that the addition of these compounds to the composition of the charge for producing the wires of the 35V9Kh3SF and 25Kh5FMS types improves a large number of the characteristics of the deposited layer: reduces the extent of contamination with non-metallic inclusions, increases the hardness of the deposited layer, refines austenite grains and results in the formation of fine-dispersion carbides which in practice may improve the thermal resistance of rolling rolls, and also prevents the formation of a ferrite network which may have a beneficial effect on cracking resistance. The experimental results can be used to develop new compositions of flux-cored wires for hardfacing rolling rolls protected by Russian Federation patents. The hardfacing technologies of the rolls using these flux-cored wires with the C–Si–Mn–Cr–W and C–Si–Mn–Cr–V–Mo alloying systems are now produced by the ElSib company.

KEYWORDS

flux-cored wire; welding deposit; microstructure; non-metallic inclusions; austenite; carbides; hardness

Russian and foreign metallurgical companies use widely the technology of reconditioning the working surface of rolling rolls by hard facing. Hardfacing by this technology greatly increases the durability of the rolling rolls. Regardless of the wide range of the grades of flux-cored wires used for hard facing, the alloying systems C–Si–Mn–Cr–W–V and C–Si–Mn–Cr–V–Mo are used in most cases [1–5].

The first alloying system is represented by the PP-Np-35V9Kh3SF flux-cored wire containing up to 10% tungsten. The rolls hard faced with this flux-cored wire are characterized by high erosion resistance at elevated temperatures, but their thermal endurance is a relatively low – the rolls hard faced with this wire often fail as a result of the formation of a network of burn cracks and chipping.

In many cases, the components contain bands of worn areas caused by the presence of areas of deposited metal with a heterogeneous structure and hardness. These areas are found in multilayer hardfacing of alloy steels with overlapping of the previously deposited beads.

Hardfacing with the flux-cored wires of the C–Si–Mn–Cr–V–Mo alloying system results in the highest thermal fatigue resistance of metal. For example, the application of the PP-Np-25Kh5FMS flux-cored wires results in high impact toughness of deposited metal at elevated temperatures [1,2].

The differences in the characteristics of the flux-cored wires determine the areas of application. For example, according to the results of laboratory and pilot plant tests,

the authors of [3] recommend to use the PP-Np-35V9Kh3SF flux-cored wire for hard-facing rolls in continuous sheet-bar-and-billet, wire and tube rolling mills, and the PP-Np-25Kh5FMS flux-cored wires in the reduction (blooming, slumping), large size and rail and beam, medium and fine grade sheet rolling mills.

It should be noted that the service life of conventional surfacing materials is now completely exhausted and extensive research is being carried out to develop new compositions of the flux-cored wires. In particular, the companies TM. VELTEK and REMMASH ChNPKF together with the metallurgical companies Krivorozhstal' KGМК, DMK im. Dzerzhinskogo and MK Zaporozhstal' are carrying out a number of investigations directed at improving the hard facing materials, technology and equipment for hard facing rolling rolls [4].

The experiments carried out to develop and improve the compositions of surfacing materials have resulted in the development of new compositions of the flux-cored wires based on Np-25Kh5FMS and Np-35V9Kh3SF wires using a carbon and fluorine-containing material – the dust from gas screening in aluminium production. The experiments carried out to use this material as an addition for welding fluxes showed that carbon in the composition of the carbon-fluorine-containing dust is characterized by higher activity, deoxidizes the metal and reduces the oxides present in the metal and the slag with the formation of carbon oxides [5,6].

Experiments in the laboratory conditions were conducted on the specimens of flux-cored wires of the PP-

Np-25Kh5FMS and PP-Np-35V9Kh3SF type replacing amorphous carbon by the dust formed in cleaning in aluminium production with the following chemical composition, wt.%: $\text{Al}_2\text{O}_3 = 21\text{--}46$; $\text{F} = 18\text{--}27$; $\text{Na}_2\text{O} = 8\text{--}15$; $\text{K}_2\text{O} = 0.4\text{--}6$; $\text{CaO} = 0.7\text{--}2.3$; $\text{SiO}_2 = 0.5\text{--}2.5$; $\text{Fe}_2\text{O}_3 = 2.1\text{--}3.3$; $\text{C}_{\text{total}} = 12.5\text{--}30.2$; $\text{MnO} = 0.07\text{--}0.9$; $\text{MgO} = 0.06\text{--}0.9$; $\text{S} = 0.09\text{--}0.19$; $\text{P} = 0.10\text{--}0.18$. Nickel powder was added to a number of specimens. Hardfacing was carried out on plates of 09G2S steel in six passes [7,8].

In the investigations, specimens of a standard composition (using amorphous graphite), specimens with a carbon-fluorine-containing addition (instead of amorphous graphite) and specimens containing both the carbon-fluorine composition and nickel powder were produced for each alloying system.

The chemical composition of the deposited metal was determined by the X-ray fluorescence method in an XRF-1800 spectrometer and the atomic emission method in a DFS-71 spectrometer.

Metallographic analysis was carried out in an Olympus GX-51 optical microscope in the bright field in the magnification range $\times 100$ – 1000 after etching the surface of the specimens in a 4% solution of nitric acid. The grain size was determined in accordance with the GOST 5639–82 standard at a magnification of $\times 100$. The grain size of martensite was determined by comparing the structure with the reference specimens of the appropriate scales and the dimensions of the martensite needles with the data from the table No. 6 of the GOST 8233–56 standard. The length of the martensite needles was determined using a package of applied programs for metallographic studies Siams Photolab 700. The presence of non-metallic inclusions in the longitudinal specimens of the deposited layer was determined in accordance with GOST 1778–70. The polished surface was examined at a magnification of $\times 100$ using a LaboMet-II metallographic microscope.

Hardness was determined by the Rockwell and Vickers methods. Rockwell hardness measurements were conducted in accordance with the requirements of GOST 9013–59. The microhardness of martensite was determined by measuring the microhardness of structural components by the Vickers method in

accordance with the requirements of GOST 9450–76. The investigations were carried out in an HVS-1000 digital microhardness metre with an automatic rotating head and digital display of data. Ten martensite microhardness measurements were taken for each specimen using the following procedure. An indenter in the form of a tetrahedral diamond pyramid was pushed into the surface of the metallographic section etched in advance. The load was 1 N. After removing the load, the hardness number was determined in accordance with the length of the diagonals of the resultant imprint. The calculation of the hardness number according to Vickers, its image on the screen of the computer and conservation of the image with the imprint were carried out automatically using a CCD camera connected to a computer with a video capture board and the appropriate software for image analysis.

The rate of erosion of the deposited layer of the experimental specimens was determined by the wear test in a 2070 SMT-1 machine. The following parameters were selected: the range of variation of the frequency of rotation of the shaft of the lower specimen (range A) $75\text{--}750\text{ min}^{-1}$; the range of measurement of the friction moment (range I) $1\text{--}10\text{ N m}$.

The results of metallographic studies show that the addition of the carbon-fluorine-containing addition to the composition of the 25Kh5FMS and 35V9Kh3SF wires reduces the level of contamination of the deposited metal with non-metallic inclusions (Figures 1 and 2): the number of banded oxide inclusions and silicates which are not deformed in the structure of the specimen greatly decreases.

The addition of the carbon-fluorine-containing compounds to the charge for the production of the 25Kh5FMS flux-cored wire results in the removal of the ferrite network (Figure 3(b)) which increases the cracking resistance of the steel and results in the formation of fine-dispersion carbides in the structure of the steel (Figure 3(d)).

The experimental results show that the addition of the carbon-fluorine-containing material instead of amorphous graphite not only improves the structure

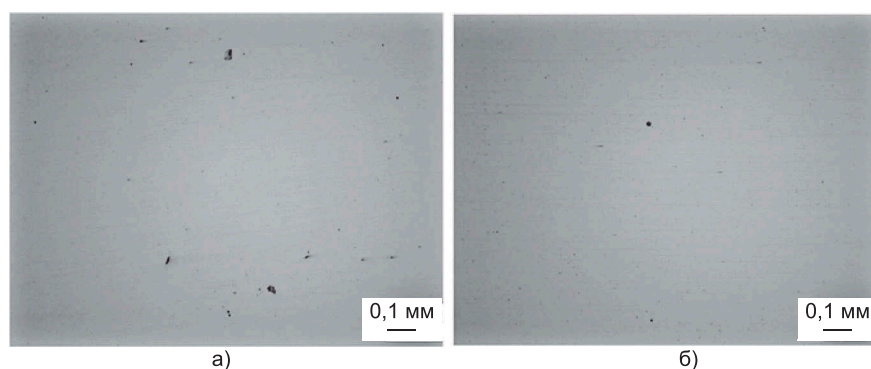


Figure 1. Non-metallic inclusions in specimens hardfaced with the 25Kh5FMS flux-cored wire: a – using amorphous graphite; b – using the carbon-fluorine additions.

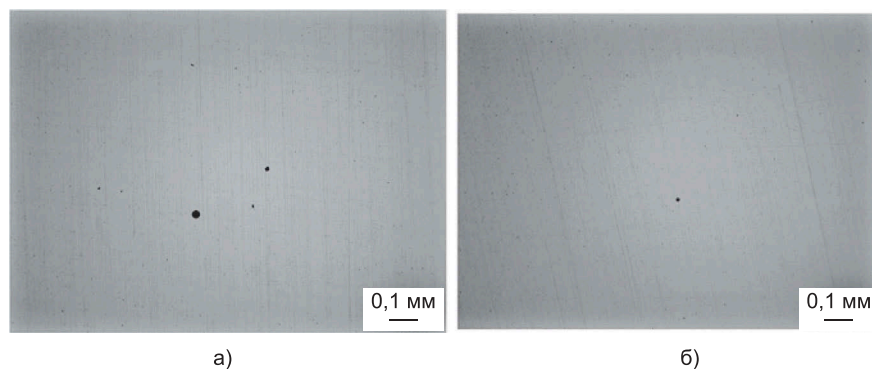


Figure 2. Non-metallic inclusions in specimens hardfaced with the 35V9Kh3SF wire: a – using amorphous graphite; b – using the carbon–fluorine additions.

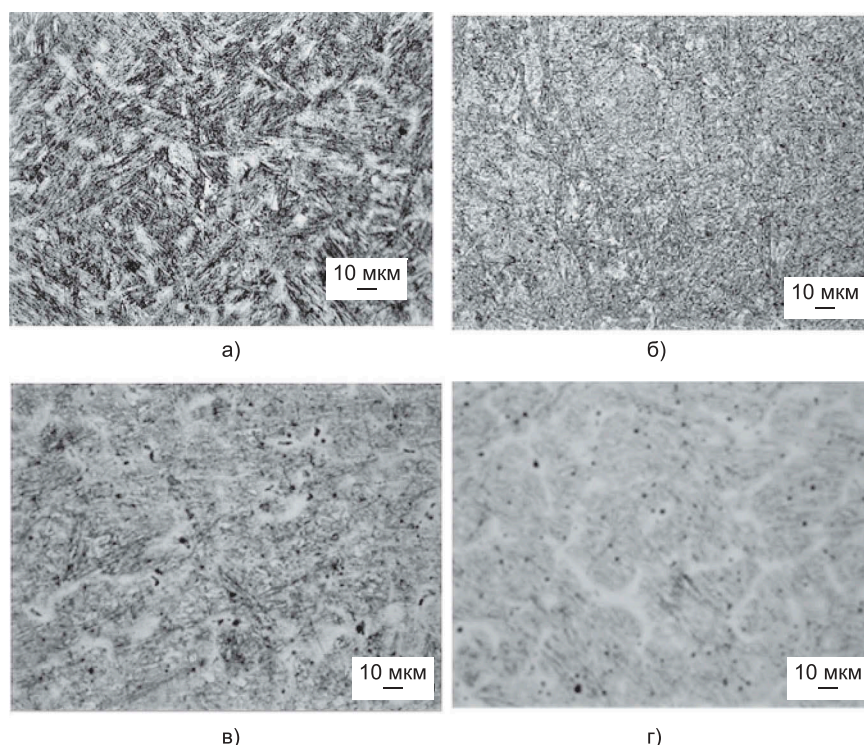


Figure 3. Microstructure of specimens hard faced with the 25Kh5FMS flux-cored wire: a, c – produced using amorphous graphite; b, d – produced using the carbon-fluorine-containing additions, mkm = μm .

but also increases the properties of the deposited layer – the average hardness of the deposited layer increases by 5% and 3% for hard facing with the 25Kh5FMS and 35V9Kh3SF flux-cored wires, respectively. The hardness of the deposited metal of the investigated specimens is given in Table 1.

To determine the effect of the chemical composition of the flux-cored wire on the hardness of the deposited metal, the experimental specimens were examined by multiple regression analysis. The following equations were obtained as a result:

$$\text{for the PP – Np – 25Kh5FMS wire} \quad (1)$$

$$\text{for the PP – Np – 35V9Kh3SF wire} \quad (2)$$

According to the experimental values, the strongest effect on the hardness of the surface of the deposited

layer in the investigated range of variation of the content of the elements is exerted by the carbon. When the carbon content of the 25Kh5FMS wire is increased by 0.1% the hardness increases by 15 HRC units, and in the 35V9Kh3SF wire by 30 HRC units. These values correspond to the generally accepted assumptions regarding the effect of carbon on the mechanical properties of steels and alloys.

The hardness of the layer deposited with the PP = Np-25Kh5FMS wire slightly increases when the silicon and titanium content of the wire was increased. Taking into account the range of variation of the content of these elements, the strength of the effect of silicon may amount up to 5 HRC units and that of titanium to no more than 1 HRC unit.

In hardfacing with the PP-Np-35V9Kh3SF wire, the increase of the hardness of the deposited layer is the

Table 1.

Flux-cored wire	Composition of flux-cored wire	Hardness of deposited layer, HRC		
		Average	Maximum	Minimum
25Kh5FMS	Standard	43,2–45,4	43,4–46,0	41,5–45,2
	With carbon–fluorine dust	45,0–48,1	45,5–48,5	45,0–47,0
35V9Kh3SF	Standard	45,5–49,0	46,0–49,2	45,2–48,7
	With carbon–fluorine dust	46,0–50,8	45,2–49,3	47,0–51,2

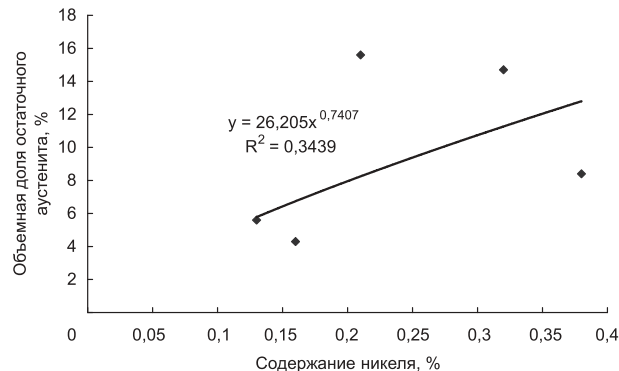


Figure 4. Effect of the nickel content of the PP-Np-25Kh5FMS flux-cored wire on the volume fraction of retained austenite in the deposited layer. Содержание никеля, % = Nickel content, %. Объемная доля остаточного аустенита, % = Volume fraction of residual austenite, %.

result of the effect of the increase of the content of elements such as titanium, vanadium and tungsten. The increase of the tungsten concentration in the investigated range is expressed in the change of hardness by up to 30 HRC units. The effect of the concentration of vanadium in titanium on the hardness of the deposited layer is considerably smaller and in absolute units equals up to 2 and 1 HRC units, respectively.

The addition of nickel to the composition of the wire increases the volume fraction of retained austenite (Figure 4) and also refines the austenite grains. This increases the thermal resistance of the deposited layer.

The experimental results were used to develop new compositions of the flux-cored wires for hardfacing rolling rolls [9,10]. The compositions are protected by Russian Federation patents and are presented in Table 2 (prototype PP-Np-25Kh5FMS) and Table 3 (prototype PP-Np-35V9Kh3SF).

Pilot plant tests of these compositions were conducted by hardfacing components for working roles with the diameter of the working part of 150 mm, length 425 mm. A wire with a diameter of 3.6 mm was used, with the filling factor of 0.32–0.33. Hardfacing was carried out under a flux in the following conditions: welding current 380–400 A, arc voltage 32–30 V, surfacing speed 25 m/h, flux-cored wire feed rate 73 m/h.

The presence of cracks in the layers during hardfacing was evaluated visually, and after hardfacing, the presence of the cracks, pores and non-metallic inclusions was determined by the ultrasound and magnetic

Table 2.

Component	Content of component, %
Sheath	67,0–68,0
Ferromanganese	0,50–1,20
Ferrosilicium	1,0–1,75
Ferrochrome	7,2–9,1
Ferromolybdenum	1,5–2,3
Ferrovandium	0,6–0,8
Carbon–fluorine-containing dust from aluminium production filters	0,70–1,20
iron powder	Balance

Table 3.

Component	Content of component, %
Sheath	67,0–68,0
Ferrotungsten	10,0–13,75
Ferromanganese	0,76–1,41
Ferrosilicium	0,26–1,34
Ferrochrome	3,38–5,38
Ferrovandium	0,4–1,0
Carbon–fluorine-containing dust from aluminium production electric filters	0,1–1,0
Iron powder	0,80–2,58
	Balance

powder methods and also on metallographic sections. The hydrogen content of the deposited metal was determined by reduction melting in vacuum or in a flow of an inert gas–carrier in a TC-600 gas analyser (LECO, USA).

No defects (cracks, pores or non-metallic inclusions) were found in hard facing with a flux-cored wire with the charge of the new composition (Russian Federation Patent Np/2518211, 2013; No. 2518032, 2013).

According to the experimental results, the hydrogen content varied in the range 0.2–0.6 cm³/100 g and 0.2–0.7 cm³/100 g of deposited metal for the wires with the composition presented in Tables 2 and 3, respectively (the permissible hydrogen content in the high-alloy-deposited metal was up to 2 cm³/100 g of metal). The low hydrogen content was explained by the efficient removal of hydrogen as a result of the addition of the fluorine-containing compounds to the composition of the carbon–fluorine-containing dust. These compounds dissociate at the temperatures of welding processes with the release of fluorine which in turn interacts with the hydrogen dissolved in the steel, with the formation of the gaseous compounds of the type HF.

The hardness of the deposited metal was 48–54 HRC and 42–46 HRC for the wires with the composition according to Tables 2 and 3, respectively. The

increase of the hardness is caused by extensive carburization during the interaction of carbon fluoride CF_x ($1 \geq x > 0$) with the carbide-forming elements. Consequently, the amount of the carbide component in the structure of the deposited metal increases.

The hardfacing technology of the rolls using the proposed flux-cored wires with the C–Si–Mn–Cr–W–V and C–Si–Mn–Cr–V–Mo alloying systems is now used in the conditions of the ElSib company.

References

- [1] Traino AI. Rational regimes of service and reconditioning of rolling rolls. *Stal'*. 2008;10:86–91.
- [2] Shebanits EN, et al. Increasing the cracking and wear resistance of hardface working roles for hot rolling. *Metallurg*. 2012;8:72–75.
- [3] Danilov LI, et al. Increasing the service life of support rolls of the 2000 strip hot rolling mill in the Severstal' company. *Chernaya metallurgiya*. 2004;8:68–69.
- [4] Matvienko VN, et al. Reconditioning by hardfacing components of metallurgical equipment in the conditions of the MKM im. Il'icha company. *Metall i lit'e Ukrainy*. 2005;7–8:66–69.
- [5] Timarenko VI, et al. Reconditioning of the rolls of rolling mills by flux-cored wire. *Svarochnoe Proizvodstvo*. 2013;7:29–32.
- [6] Kondrat'ev IA, et al. Investigation of the structural heterogeneity of the deposited metal of the type 35V9Kh3SF and its effect on the efficiency of hardfaced rolling rolls. *Avtomaticheskaya Svarka*. 1996;6:17–20.
- [7] Kondrat'ev IA, et al. Arc and electroslog hardfacing of the rolls of rolling mills. *Remont vosstanovlenie modernizatsiya*. 2005;4:14–17.
- [8] <http://www.tm-veltek.ru>.
- [9] Kozyrev NA, et al. Investigation and development of new carbon–fluorine containing additions for welding fluxes. *Chernaya metallurgiya*. 2015;4:258–261.
- [10] Kozyrev NA, Kryukov RE, Kryukov NE et al. Technological aspects of application of the carbon–fluorine addition in submerged-arc welding. *Svarochnoe Proizvodstvo*. 2015;4:43–47.