

On Quality of a Weld Bead Using Power Wire 35v9h3sf

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Abstract: The effect of introducing carbon-fluorine containing additives and nickel to flux-cored wire 35V9H3SF on its structure, micro hardness of martensite, hardness and wear rate of a welded layer has been investigated. It has been proven that carbon-fluorine additions to a powder mixture increase the hardness of the deposited layer and its wearing strength. Nickel adding increases the hardness of both martensite and the deposited layer, and reduces abrasion wear. Introducing carbon-fluorine containing additives to the powder mixture can reduce the pore formation and lower the level of impurity with nonmetallic inclusions; and nickel adding can lead to austenite having a finer grain size.

1. Introduction

Nowadays, the flux-cored wire PP-Np-35V9H3SF is widely applied in the process of hard surfacing rollers of mill tables and rolls used in hot rolling mills. However, the surfacing process, when using this welding wire, is accompanied by a number of unacceptable defects: pores, cavities, macroscopic nonmetallic inclusions; and in some cases hardness decreases causing a shorter operational life of rolls [1].

It is widely known that sodium fluorosilicate is added to powder wire to reduce pore formation as a result of lower concentrations of hydrogen [1], gas- and slag-forming substances are added to protect against atmospheric gases, and low ionization potential elements are added to ensure stable arcing [2- 4].

2. Results and discussion

Under a laboratory environment, carbon-fluorine containing dust (metallurgical waste) was used instead of amorphous graphite to make samples of flux-cored wire with the following chemical composition, by weight, %: Al₂O₃ = 21-46; F = 18-27; Na₂O = 8-15; K₂O = 0.4 – 6%; CaO = 0.7-2.3; SiO₂ = 0.5-2.5; Fe₂O₃ = 2.1-3.3; C_{total} = 12.5-30.2; MnO = 0.07-0.9; MgO = 0.06-0.9; S = 0.09-0.19; P = 0.10-0.18. It has been experimentally established earlier that carbon in a carbon-fluorine containing addition has a higher activity, deoxidizes metals, and reduces oxides in metal and slag to form carbon oxides [5, 6]. For making a powder mixture used for the wire production, the following components and powders were used: amorphous carbon, carbon ferromanganese FMn 78 (A), ferrosilicon FS 75, high carbon ferrochrome FH 900A, ferrovandium FV50U0,6, nickel PNK-2K9, and iron PZHV1. The surfacing process was conducted using the AN-26S flux.

An X-ray fluorescence spectrometer XRF-1800 and an atomic emission spectrometer DFS-71 were used to determine a chemical composition of the welded layer. The obtained results are given in Table 1.



Longitudinal specimens of the weld deposition were analyzed according to the standard technique relating to the presence of nonmetallic inclusions. A metallographic microscope LaboMet-II was used to study a polished surface at 100X magnification. Metallographic studies are performed using an optical microscope OLYMPUS GX-51 in bright field at various magnifications after etching with a solution of alcohol and nitric acid. The grain size was evaluated according to the standard test method at 100X magnification. Martensite structure was analyzed using the standard comparison charts to rate sizes of martensite needles. A metallographic test program Siams Photolab 700 was used in determining the length of martensite needles and pore sizes.

Table 1-Chemical analysis of test specimens in 35V9H3SF material

Test No	By wt, %													
	C	Si	Mn	Cr	Ni	Cu	Ti	W	V	Mo	Al	Co	S	P
1	0.14	0.45	1.69	2.60	0.08	0.02	0.005	8.84	0.36	0.01	0.019	0.11	0.028	0.022
2	0.14	0.51	1.73	2.09	0.08	0.11	0.005	7.66	0.14	0.01	0.012	0.11	0.029	0.021
3	0.13	0.45	1.74	2.18	0.38	0.09	0.005	8.11	0.09	0.01	0.008	0.11	0.034	0.019
4	0.13	0.49	1.68	2.27	0.46	0.09	0.004	8.21	0.13	0.01	0.005	0.11	0.034	0.023
5	0.13	0.60	1.54	2.66	0.58	0.09	0.005	7.58	0.15	0.02	0.044	0.11	0.040	0.020
1 – The test specimen with amorphous carbon added. 2 The test specimen with carbon-fluorine containing additives.														
3,4, 5 – The test specimens with carbon-fluorine containing additives and nickel.														

According to the study performed, spots of oxides with grain size number 1a (Figure 1 a, c, d, e) and number 2a (Figure 1 a, e), represented in the form of single particle inclusions, are predominantly observed in the test specimens. Almost all the specimens under study have non-deformable silicates in the form of rounded and irregularly shaped inclusions with grain size number 1a (Figure 1, b), 2a (Figure 1, f) and 2b (Figure 1, e, f).

There are spot oxides with grain size numbers 1a and 2a (Figure 1a) and non-deformable silicates with grain size number 1a (Figure 1b) observed in test specimen No.1, with amorphous graphite being used as an additive. Spot oxides with grain size number 1a (Figure 1, c) are observed in test specimen No.2 with carbon-fluorine containing additives. Examining test specimen No.3 shows the presence of oxides with grain size number 1a (Figure 1, d). There are spot oxides with grain size numbers 1a and 2a (Figure 1,a) and a small amount of non-deformable silicates with grain size number 2b (Figure 1,e), observed in test specimen No.4. Specimen No.5 has non-deformable silicates with numbers 2a and 2b (Figure 1, f).

Thus, it has been established that adding carbon-fluorine containing material instead of amorphous graphite to the powder mixture reduces the degree of contamination of steel with nonmetallic inclusions. In this connection, only spot oxides are present in the structure, and non-deformable silicates are not observed. Spot fine carbides are traced in all examined test specimens.

Metallographic analysis revealed that test specimen No. 1, with using amorphous graphite as an additive, has a structure of a coarse acicular martensite (number 10) and residual austenite that is present in a small amount (Figure 2,a). The grain size corresponds to numbers 6 and 7 in the comparison chart used for grain size rating. In this case, porosity is observed over the entire polish surface. The pore size varies 640 - 1077 micrometers.

After adding carbon – phosphorus containing material instead of amorphous carbon to the powder mixture (test specimen No. 2), ferrite in the form of a separate structural constituent and of a grid in some areas is determined, in addition to a coarse acicular martensite (number 10) and residual austenite in a small amount (Figure 2,b). The grain size corresponds to numbers 5 and 4 according to the comparison grain size chart. In this case, a decrease in porosity is established.

After adding 0.38% nickel to the powder mixture (test specimen No. 3), there is coarse acicular martensite (number 10), residual austenite, and the ferrite component observed in the structure as well (Figure 2,c). The grain size corresponds to numbers 5, 6 and 7 according to the comparison grain size chart. Using carbon-fluorine containing additives and 0.38% nickel does not cause the porosity formation.

The addition of carbon-fluorine containing material and 0.46% nickel (test specimen No.4) to the powder mixture results in the structure, consisting of coarse acicular martensite (number 10), ferrite in the form of separate structural component (Figure 2,d), and a small amount of residual austenite (Figure 2, d, e). The grain size corresponds to numbers 5, 6 and 7 according to the comparison chart; porosity is not observed.

When adding 0.58% nickel (test specimen No.10) to the powder mixture, the ferrite component is not determined in the structure. The structure consists of coarse acicular martensite (number 10) and a small amount of residual austenite with grain size numbers 6 and 7 (Figure 2, f). Martensite has a dispersed structure in comparison with other test specimens; the size of martensite needles is 7-42 microns. In this case, a decrease in porosity is observed.

Thus, it is established, when carbon-fluorine containing additives are used without or with 0.38 % and 0.46% nickel to replace amorphous graphite, the ferrite structure is mainly observed in the form of a separate component as well as coarse acicular martensite and residual austenite. A ferrite-free structure can be obtained when carbon-fluorine containing materials and a larger amount of nickel (0.58%) are used for the wire powder. It should be noted that, when nickel is not used while adding carbon-fluorine material to the wire powder, the austenite grain size increases. The use of carbon-fluorine containing additives separately or together with nickel in an amount of 0.38, 0.46 and 0.58 % reduces porosity in the surfacing material made of steel 35V9H3SF.

The hardness was defined using the Rockwell and Vickers methods. The test method capable to determine the microhardness of structure components was utilized in examining the properties of martensite. A HVS-1000 automatic digital micro hardness tester was used for determining microhardness. 10 measurements were taken to evaluate microhardness of martensite.

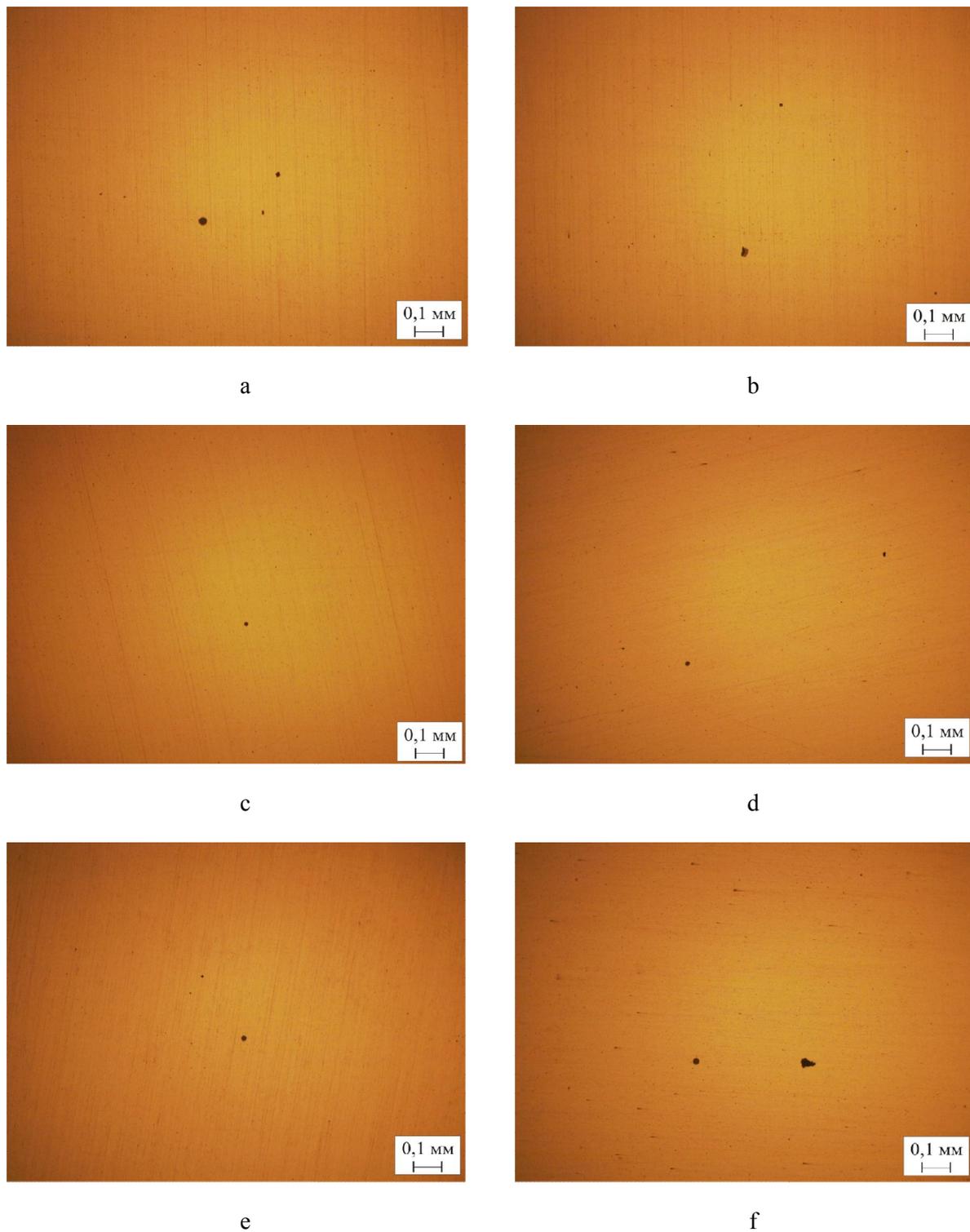


Figure 1- Nonmetallic inclusions: a, b – test specimen No.1; c – test specimen No.2; d – test specimen No.3; e – test specimen No. 4, f – test specimen No. 5

An etched metallographic polish was prepared for analyzing the structure using a microscope. Within the selected area to be observed, a diamond indenter was pushed to make indentation under a load of 1 H; and then the size of the indent on the polished surface was measured using a microscope. Calculating and displaying the hardness number according to the Vickers hardness test method as well as saving images of indents were automatic, enabled by the connection of a CCD-camera with a video capture card to the computer and relevant software to analyze images.

A 2070 SMT – 1 tester was used to measure the wear rate of the deposited layer. In this case, the following parameters were selected: a measurement range for frequency of rotation of shaft with the lower sample (range A), which is 75 -750 min⁻¹, and measuring range for friction torque (range I), which is 1 - 10 N/m.

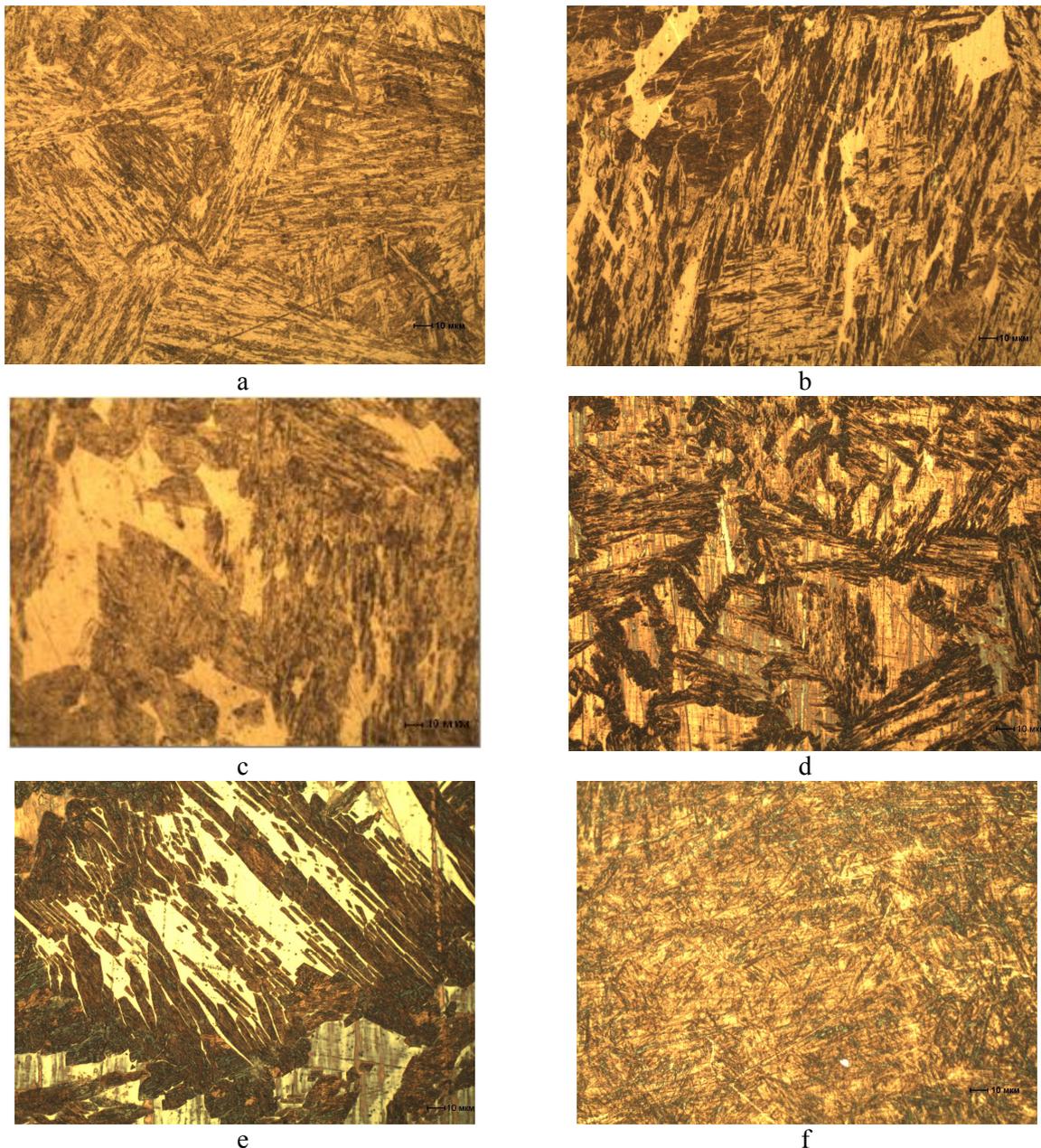


Figure 2 Microstructure, $\times 500$: a, b – test specimen No.1; c – test specimen No.2; d – test specimen No.3; e – test specimen No. 4, f – test specimen No. 5

Metallographic examination of test specimen No.1, where amorphous graphite was used as an additive, revealed that its structure contained coarse acicular martensite (number 10) and a small amount of residual austenite. The microhardness of martensite is 471 HV. Images of the indents for determining microhardness are shown in Figure 3.

The average value of hardness of the deposited layer corresponds to 45,5HRC, and the rate of its wear makes 0.00088 g/min.

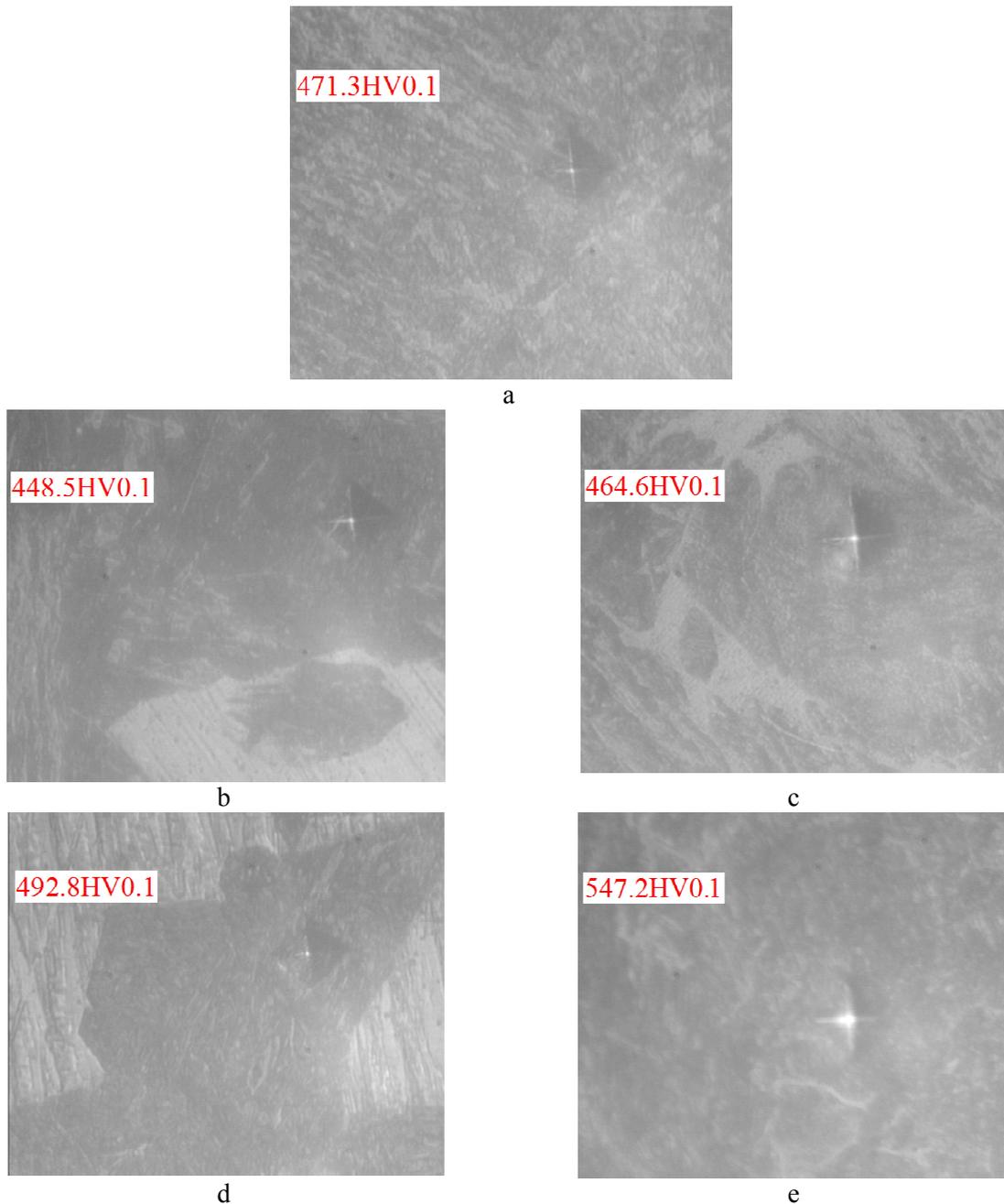


Figure 3 Microhardness of martensite in the specimens under study: a - the specimen with the addition of amorphous graphite; b - the specimen with the addition of carbon –fluorine containing dust; c - the specimen with the addition of carbon –fluorine containing dust and 0.38% nickel; d - the specimen with the addition of carbon –fluorine containing dust and 0.46% nickel; e - the specimen with the addition of carbon –fluorine containing dust and 0.58% nickel

Adding carbon – phosphorus material to the powder mixture (test specimen No.2) to replace amorphous carbon promotes the appearance of ferrite in the form of a structural component and a grid in some areas, besides acicular martensite (number 10) and a little residual austenite. Using carbon-phosphorus additions reduces the microhardness of martensite by 5%, compared with test specimen No.1 (Table 2). However, with this, the hardness of the deposited layer increases, and the rate of wear reduces.

Table 2 – Microhardness of martensite in the test specimen structures, hardness and wear rates of the deposited weld

Test specimens No.	μ_H , HV	HRC average min/max	Wear rate, g/min
1	471	$\frac{45,5}{45,2/46,0}$	0,00088
2	449	$\frac{46}{45,2/47,0}$	0,00052
3	464	$\frac{45,5}{45,2/47,0}$	0,00052
4	493	$\frac{47,2}{45,0/49,0}$	0,00065
5	547	$\frac{48,0}{46,5/50,0}$	0,00068

When adding 0.38 and 0.46% nickel (specimens No.3 and 4) to wire, besides needle-like martensite grains (grain size number No.10) and a small amount of austenite grains, the ferrite component is present in the structure. Adding nickel in amount of 0.58% (specimen No.5) provides refinement of martensite needles and makes a ferrite-free structure, consisting of coarse needles of martensite (grain size number No.10) and residual austenite. In specimen No.5 martensite has a more dispersion structure (the size of martensite needles is 7 - 42 microns), if to compare with other specimens, where the size of needles in the martensite structure is not possible to measure. Besides, when comparing with specimen No. 2, adding 0.58% nickel increases the microhardness of martensite by 22% and the hardness of the welded layer by 4%. Additional introduction of nickel in an amount of 0.46 and 0.38% increases microhardness of martensite to a lesser extent (by 19 and 3%, respectively). Adding 0.46% nickel increases the hardness of the welded layer by 2% as compared with specimen No.2. Using carbon - phosphorus containing admixtures to replace amorphous carbon, separately and together with nickel, reduces the rate of wear relating to the welded layer.

The described researches form the basis for making the flux-cored wire, the chemical composition of which is protected by the Russian patent. [7].

Conclusions

1. Adding carbon-fluorine containing material and nickel instead of amorphous graphite to the 35V9H3SF flux-cored wire increases the hardness of the welded layer and reduces the rate of its wear.
2. Adding nickel to the powder mixture improves microstructure due to the removal of ferrite and refinement of martensite that is accompanied by a significant increase in microhardness and a slight increase in hardness of the welded layer.
3. New flux cored wire for surfacing steel is based on the results of this research.

This work has been done at Siberian State Industrial University in the framework of government contract No. 11.1531/2014/K with the Ministry of Education and Science RF. The equipment of the Common Use Centre "Material Science" at SibSIU was used in tests, researches and measurement.

References

- [1] I I Frumin, Yu A Yuzvenko, E I Leynachuk.. Tehnologija mehanizirovannoj naplavki [Machine Disposition Technology] . – Moscow : Vysshaya Shkola,1964.- 306p.
- [2] Konovalov A V, Kurkin A S, Makarov E L, Nerovniy V M, Yakushin B F Teorija svarochnyh processov [Theory of Welding processes] - Moscow.: Bauman MSTU Publ., 2007. - 752p.
- [3] Kuznetsov M A, Zernin E A , Danilov V I , Kartsev D S Application of nanostructured powders to control characteristic of electrode metal transfer and the process of weld structurization // Applied Mechanics and Materials. - 2013 - Vol. 379. - pp.199-203.
- [4] N P Aleshin, G G Chernyshov, A I Akulov and colleagues. Svarka. Reзка. Kontrol': Spravochnik.[Welding.Cutting. Control: Handbook in 2 Vol] - Moscow: Mashinostroenie, 2004. Vol.1, 624 p.
- [5] Kozyrev N A, Kryukov N E, Kryukov R E, Igushev V F, Koval'skiy I N Tehnologicheskie aspekty ispol'zovaniya uglerodftorsoderzhashhej dobavki pri svarke pod fljusom [Technological Aspect of Carbon-Fluorine Adding in flux welding]. Svarochnoe proizvodstvo. – 2015. – No. 4. – pp. 43-47.
- [6] N A Kozyrev, R E Kryukov, O A Kozyreva 2015 IOP Conference Series: Materials Science and Engineering 91 New tendencies in development of carbonaceous additives for welding fluxes doi:10.1088/1757-899X/91/1/01/012008.
- [7] Kozyrev N A, Igushev V F, Titov D A, Kozyreva O E, Starovatskaya S N Patent RU 2518211, MPK8 V23 K35/368 Poroshkovaja provoloka [Powder Wire].