

Microstructure of low-carbon steel wire and its welding and fabrication properties

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Abstract

In this paper, we researched the impact of wire rod structure homogeneity on arc stability of welding wire. The microstructural analysis was carried out for low-carbon welding wire in its sections with steady and unsteady arc burning and it showed that equal distribution of carbide phase in ferrite matrix complied with the best arc burning. The presence of coagulated carbides in microstructure was typical for sections with unsteady arc burning. The results of Vickers hardness measurement evidenced that the best arc burning was appropriate for wire samples, characterized by increased and steady hardness.

The increased welding wire porosity could be caused by presence of gases in it (the increased concentration of nitrogen was found there) and it stipulated wire hardness decrease and unsteady arc burning as a result.

Key words: MICROSTRUCTURE, WELDING WIRE, WELDING AND FABRICATION PROPERTIES, ARC BURNING STABILITY, CARBIDES, HARDNESS, PORES, WIRE ROD, YIELD CURVES, COEFFICIENT OF HARDENING

Stability of welding wire arc burning is one of the most important characteristics of its welding and fabrication properties. For the consumers, this is the top priority index of product quality. The unsteady arc burning has the effect on the geometrical parameters

of welding seam, chemical composition of welded metal and as a result, on mechanical properties of welding structures [1].

The reasons for unsteady arc burning can be related to the quality of electrode wire: insufficient copper coat

adhesion and its inhomogeneity, deviations from the diameter and its very low hardness [2, 3].

During the course of production, PJSC PlasmaTec faced a problem when certain copper wire coil had alternating sections with staggered unsteady and steady arc burnings. Moreover, the parameters of production process were regular, and the wire completely met the standard requirements. The possible reason of this phenomenon could be the differences in microstructure of the mentioned sections. Indeed, there exist explanations on the reasons why wire rod breakage takes place during the process of drawing and they are conditioned upon structure factors mentioned in papers [4, 5]. However, the mentioned sources do not describe the influence of wire micro-

structure and mechanical properties on its welding and fabrication properties.

Owing to this problem, the present article concentrates on the purpose to analyze results of the microstructural and X-ray analyses of the welding wire samples characterized by steady and unsteady arc burning.

The metallographic researches were conducted for five samples of G3Si1 welding wire (analog of Sv-08GS grade) with the diameter of 0.8 mm. More detailed information on them is in Table 1. Sample No. 5 served for comparison and was taken from Chinese producer wire, which has been enjoying the demand on welding materials market and possesses good welding and fabrication properties.

Table 1. Research samples

Sample No	Heat No	Wire rod producer	Welding and fabrication properties and arc burning
1	21181	LLC "NLMK-Metyz", Russia	steady
2	21181	LLC "NLMK-Metyz", Russia	unsteady
3	260399	Arcelor Mital, Kryvyj Righ, Ukraine	steady
4	260399	Arcelor Mital, Kryvyj Righ, Ukraine	unsteady
5	-	Chinese producer wire	steady

The samples inspection and photographing of microstructures were carried out on NEOPHOT-22 light microscope with the use of OLYMPUS digital camera at different magnifications. Vickers hardness measurement was conducted at M-400 microhardness tester by LECO company at loads of 100 g and 1 kg. The hardness measurement results are given in Table 3. The carbide particles size measurement was performed with VERSAMET microscope at magnification $\times 1500$. It should be noted that the contami-

nation with nonmetallic inclusions of samples No1–No5 was almost similar and it corresponded to rate No.1 according to the scale GOST 1778-70 "Oksydy tochkovi" (Spot Oxides).

In order to reveal the microstructure of the samples, the microslices of the material were etched chemically in 4% alcohol solvent of nitrogen acid.

The results of microstructural analysis of welding wire samples are shown in table 2.

Table 2. Welding wire microstructural analysis

Sample No	Microstructure features		
	Microstructure type	Carbide maximal size, μm	Average carbide size, μm
1	Disperse ferritic-carbide mixture. Carbides are uniformly distributed on all the area of the polished section	1.2 ... 1.5	approximately 1
2	Ferritic-carbide mixture. In structure, there are coagulated carbides in the form of dark regions in microstructure	0.8 ... 1.0	approximately 0.5 ... 0.8
3	Uniformed distribution of carbide constituents with small regions of coagulated carbides and chains of carbides	approximately 1 μm (discretely with the size of up to 2 μm)	less than 1
4	Ferritic-carbide mixture with small amount of coagulated carbides	2.5 ... 3	1.2 ... 1.5
5	Uniformed ferritic-carbide mixture	approximately 2.2	1.8 ... 2.0

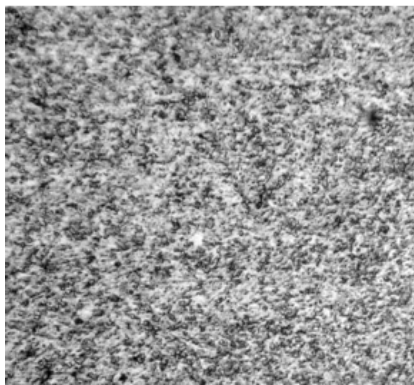
Table 3. Results of Vickers hardness measurement

Sample No	Vickers hardness, 100 g, kgf/mm ²	Integral Vickers hardness, 1 kg, kgf/mm ²
1	282; 283; 283; 283; 283	318; 318; 318
2	258; 258; 258; 258; 254; 274; 285; 274; 285; 285; 285; 236; 285	321; 317; 317
3	309; 322; 322; 322; 297; 297; 322	320; 328; 327
4	297; 297; 274; 274; 274	320; 325; 318
5	357; 357; 357; 357; 357	370; 370; 370

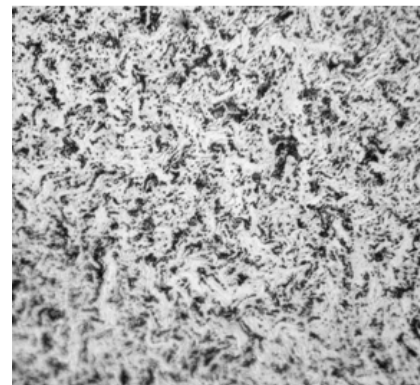
Figure 1 illustrates the microstructure of welding wire samples taken from wire rod of heat 21181. They showed steady (sample No1) and unsteady (sample No2) arc burning. The results of microstructural analysis evidenced that the samples with uniformed ferritic-carbide structure had the best arc burning while welding wire samples with unsteady arc burning had

coagulated carbides in their structure, which were observed as dark regions of the microstructure.

The results of Vickers hardness measurements (Table 3) witnessed that enhanced and steady hardness of welding wire were the characteristics of the samples with the best arc burning.



a)



b)

Figure 1. Microstructure of welding wire x1000

a) sample No1; b) sample No2

In order to find the causes of differences in samples microstructures and hardness values, methods of electronic microscopy and X-ray analysis were used. The microstructure study and the analysis of quantity element composition were carried out using scanning electron microscope study and X-ray microanalysis on the base of analytical complex, composed by scanning JSM-35CF electron microscope by JEOL (Japan) and X-ray diffraction instrument with dispersion on X-ray photon energy (model INCA Energy-350 by Oxford Instruments, the UK). The specific feature of X-ray microanalysis is in its local approach - the maximal excitement is 1 micron. The images were obtained in modes of secondary electron imaging (SEI) and backscattered electron imaging (BEI) at U = 20 kV.

The research of microstructure was performed at magnifications x600, x2000, x6000, x20000 with the

samples, on which hardness measurements were made: there are rhomboidal imprints from diamond spheroconical penetrator of hardness measuring instrument seen in the photos. The images were taken in secondary electrons, which allowed us to analyze surface texture. The quantity element composition was analyzed on both microregions (at magnification x600) and locally separated structural constituents (at magnification x20000). All the results are submitted in % (mass).

The results of element composition macroanalysis are presented in Table 4. They bring the conclusions that all the five samples had similar quantities of the main alloying elements (Si, Mn). Although it is necessary to note that this analysis cannot help us to determine the exact amount of carbon in the metal because of surface effect, that is why it was excluded from the analysis.

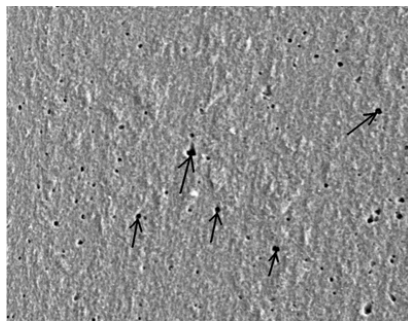
Table 4. Chemical composition of samples

Sample	Si	Mn	Fe
No1	0.79	1.57	97.64
No2	0.68	1.60	97.72
No3	0.59	1.61	97.81
No4	0.82	2.10	97.07
No5	0.91	1.70	97.39

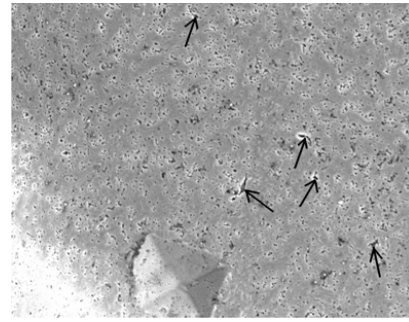
The results of microscopic study for the five samples at the same magnification (x2000) are shown in Figure 2. Based on these data, we can conclude that samples No 1-No 4 had pores. In the respective figu-

res they are in form of black spots, the biggest ones are pointed by black arrows. Sample No5 had no porosity.

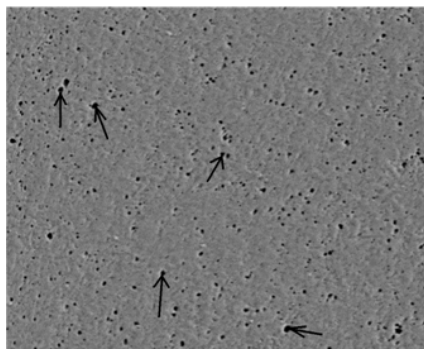
Moreover, samples No1 and No3 were similar with their low density, pores round shapes and small sizes. Sample No 2 had the highest level of pores concentration, and although their sizes were not very big, but many of them were elongated and crack-shaped with sharp edges. The pores concentration in sample No 4 was not very high, but their sizes were the biggest, they were elongated in the shape of wormhole, probably the result of pore chains fusion.



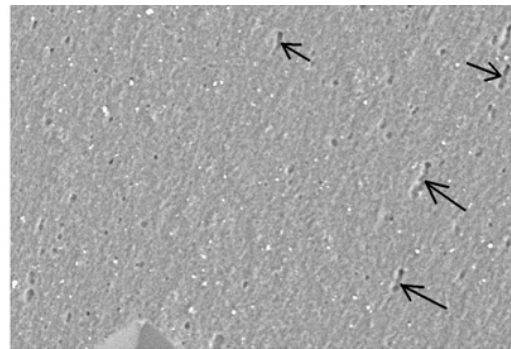
20 micron x2000
No 1



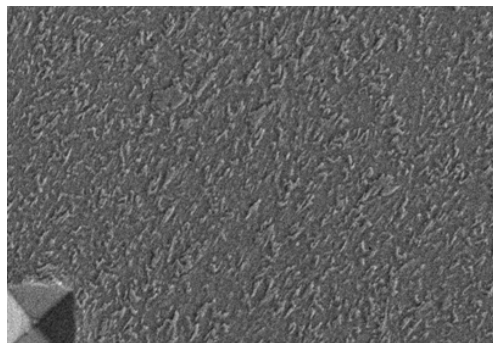
20 micron x2000
No 2



20 micron x2000
No 3



30 micron x2000
No 4



30 micron x2000
No 5

Figure 2. Sample surfaces in the mode of secondary electrons at the similar magnification x2000

In order to reveal the specific reasons of pores occurrence, we carried out the local analysis of element composition. The analysis was made inside the pores and on the metal matrix outside the pores. It was found out that the content of Si, Mn, Fe in the middle of pores was similar to metal matrix composition (the deviation was not more than 10...15%), and it drew the speculation that the pore occurrence was probably conditioned upon gases. That is why the extra studies on samples No 2 and No 5 were made with the objective to analyze gases (oxygen, hydrogen, nitrogen). The contents of oxygen and hydrogen in the test samples were similar, but that of nitrogen was significantly different (sample No2 – 0.0107%, sample No5 – 0.0050%). The high nitrogen in sample No 2 prompted that the found porosity was conditioned upon this gas.

Furthermore, the significant point in good quality wire production is the preliminary inspection of mechanical properties of the product - wire rod at feed unit. The possibility to reveal the welding and fabrication properties on the stage when the production process is being developed is of particular interest. As the quality inspection of the mechanical characteristics is not a complicated process, the opportunity to apply it for the purpose to predict the product's welding and fabrication properties is attractive. One of the

most important characteristics of the material plasticity is its yield curve or hardening one, according to which we can calculate the performance characteristics, carry out the simulation of FEM and study the mechanics of the drawing process. The nature of yield curves is not dependent on deformation type, with which they are made, their construction can be conducted on the base of the simplest tests, and results can be used for the analysis of the most complicated processes.

In order to define the mechanical properties of the wire rod of heats No. 21181 and No. 260399, tensile tests were carried out at IP100 tensile testing plant, in accordance with ISO 6892-1 Metallic Materials - Tensile Testing - Part 1: Method of Test at Room Temperature. IP100 tensile testing plant had gained metrological check certificate. We tested the samples of the wire rod prepared to the delivery. The gauge section was 200 mm and the diameter was 5.5mm. Visually, these yield curves of G3Si1 wire rod (heats No 21181 and No 260399) are shown in Figure 3. The curves were developed in accordance with the method described in paper [6]. In Table 5, we report on the values of calculated approximation coefficients and give the material standard mechanical characteristics, provided by tensile testing.

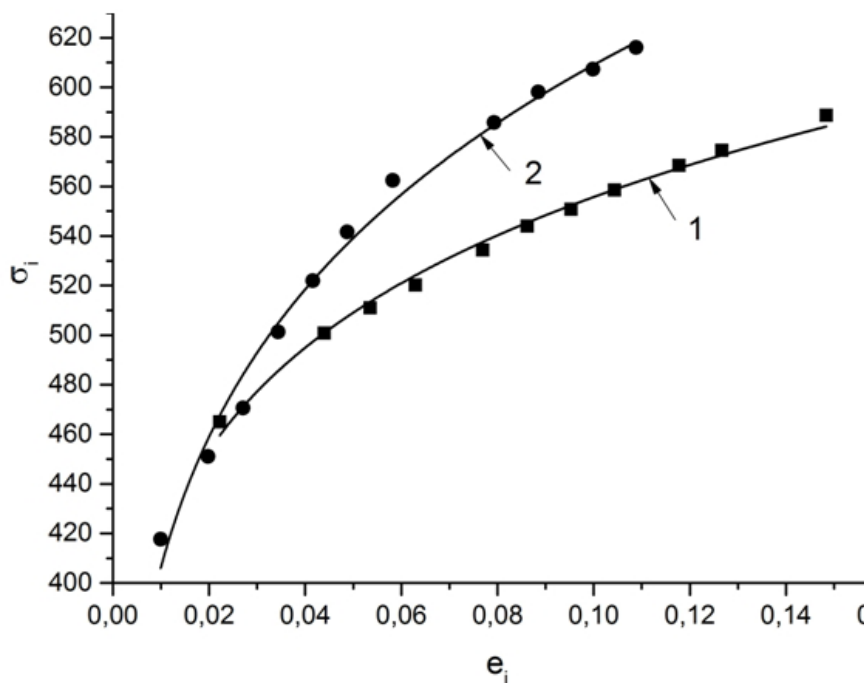


Figure 3. Continuous lines of yield curves (curve 1 – heat No. 21181; curve 2 – heat No. 260399 and σ_i , MPa)

$$\text{approximated by } \sigma_i = A e_i^n$$

Table 5. Values of approximation coefficients and standard mechanical properties

Curve No	Values of approximation coefficients			Mechanical properties		
	A , MPa	n	R_{adj}^2	σ_{rp} , MPa	σ_{hp} , MPa	Δl , %
1	744±7	0.126±0.004	0.992	507	450	30.25
2	913±18	0.176±0.006	0.988	552	425	25

The specific feature of the materials under analysis was a relatively low hardening coefficient n (0.12...0.18), which was much lower than that for the materials, studied by us earlier, in paper [6] and for which there was no obvious impairment of the wire welding and fabrication properties. This fact can speak for the following: low hardening (coefficient n is less than 0.18) of the wire rod material in the feed unit indicated the possible decrease of the finished wire quality due to the unsteady arc burning.

The obtained yield curves show that in the initial state, the wire rods physical and mechanical properties were significantly different, this was conditioned upon certain difference in the chemical compositions and processing of semi-finished products. Thus, it allows us to conclude that although the initial physical and mechanical properties of the wire rod were formed through chemical compositions within the standard requirements, they could hardly influence welding and fabricated characteristics provided that such finished products met the quality requirements. The production route and the tradition of wire rod manufacturing plays a significant role in its further processing into good quality wire. This particularly concerns the presence of included gases or pores, coagulated carbides, et cetera. Moreover, the presence of pores in the wire rod directly decreases hardening property of metal at its. In its turn, pores in material of wire rod in the feed unit condition their presence in the structure of the wire. This peculiarity can be put into the basis of express diagnostics of the material of the wire rod. The case when hardening coefficient n of the material in the feed unit is less than 0.18 (at yield curve approximation according to two-parameter Ludwig function) could mean possible decrease in the finished wire quality in terms of arc burning instability. Such cases require additional control of finished products, for instance, by way of hardness measurement carried out on different sections of the wire or its microstructural analysis.

Conclusions

The stability of welding wire arc burning is provided

not only with the appropriate finished product parameters, which usually correspond to the existing standards, but also with homogeneity of the wire rod structure, which is used by the wire producer during the process of the wire manufacture. Microstructural analysis of low carbon welding wire, carried out on its sections with steady and unsteady arc burning, showed that equal distribution of carbide phase in ferrite matrix corresponds with the best arc burning.

The high porosity of welding wire can be generated by the presence of gases in it (the high concentration of nitrogen was found in the samples) and it causes the decrease in wire hardness and unsteady arc burning.

The results of Vickers hardness measurement showed that the best arc burning is peculiar to wire samples characterized by enhanced and regular hardness.

Provided that hardening coefficient n of the wire rod material in the feed unit is less than 0.18, we can predict possible decrease in the finished product performance that is instability of arc burning.

Based on the results of microstructural analysis of welding wire, it is worth to note that the presence of coagulated carbides in its microstructure is typical for the sections with unsteady arc burning.

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