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The effect of the parameters of submerged arc surfacing with oscillating electrode on a padding weld forming, depth of fusion penetration and the content of parent metal in a weld

Abstract

The effect of oscillating movement amplitude and frequency of electrode wire swinging on forming of pad weld runs, the character of parent metal penetration, as well as structural and chemical inhomogeneity in the zone of intermixing padding weld with parent material has been tested while submerged arc surfacing using oscillating electrode. It has been stated that along with increasing frequency of electrode wire end oscillations and the same amplitude and surfacing speed, the weld run formation is improved, the width of the zone of padding weld intermixture with parent material is reduced and more dispersive structure with lower structural and chemical inhomogeneity in a padding weld is being formed. More uniform fusion penetration into the parent material and alignment of fusion line can be observed. Those relations remain practically unchanged with increasing amplitude of oscillation.

Keywords:
submerged arc surfacing with oscillating electrode;
run formation;
inhomogeneity of padding weld metal

Introduction

It is known that in some cases, in order to reduce the metal penetration of the material and to obtain wide and relatively short runs, arc welding is carried out with the pendulum movement of the electrode wire or tape [1÷4]. In these works, fundamental attention was paid to studying the influence of the amplitude and frequency of fluctuations in the electrode wire or tape on the formation of pad weld runs. However, if we take into account the fact of the direct interaction of the welding arc with the parent material during lateral fluctuations of the electrode wire, it should be expected that the character of metal penetration can change along the length of the pad weld runs. As stated earlier [5,6], uneven metal penetration can lead to a decrease in fatigue life of surfaced elements during their operation under cyclic loading conditions.

The analysis shows that if the electrical parameters of the surfacing process are not taken into account, the amplitude and frequency of the electrode wire or tape fluctuations as well as the surfacing speed have a fundamental influence on the above characteristics of pad weld runs. Moreover, all these characteristics are interrelated, and when changing one of them, two other characteristics have to be corrected in order to obtain qualitative pad weld runs.

The purpose of this work was to study the impact of the submerged arc surfacing speed, frequency and amplitude of wire fluctuations on the forming of padding welds, depth and character of metal penetration of the native material, and coefficient of the contribution of native material in the surfaced layer (degree of mixing γ).

In the further part of the article, the term is used: intermixing of the padding weld with parent material (also referred to as transition zone, fused zone, mixing zone) − this is a zone with variable chemical composition, which arises due to a significant difference in the chemical composition of the combined materials. The chemical composition of the padding weld at the border with the base material changes stepwise.

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Table I. The effect of surfacing speed, amplitude A and oscillation of electrode wire frequency N on the dimensions of surfaced runs and ratio of mixture γ

Sample no	Fluctuations		Surfacing speed, m/h	Dimensions of the runs, mm			γ, %
	A, mm	N, min^{-1}		Width	Height	Amount of penetration	
1	25	28	7	38.8	3.4	1.7	39
2*	25	45	7	36.4	2.95	1.6	37
3	40	18	7	46.8	2.05	1.8	54
4	40	32	7	47.0	1.8	1.5	50
5	25	28	10	37.5	1.9	1.8	55
6	25	45	10	35.8	2.7	1.5	52
7	40	18	10	42.6	2.1	1.5	50
8	40	32	10	44.7	1.5	1.4	49

Note: * – sample surfaced at the optimum settings of the technological parameters of the process was marked

Technological conditions of surfacing

The tests were carried out using PP-Np-25H5FMS flux-cored wire (ПП-Нп-25Х5ФМС) according to GOST 26101-84 (EN 14700 T Fe8 classification) with a diameter of 2.6 mm and AN-26 flux (АН-26) according to GOST 9087-81. The chemical composition of the weld metal corresponds to the tool steel 25H5MSGF. Parameters of surfacing: current intensity 320 A, arc voltage 32 V, wire feed speed – 3.0 m/min, wire extension – 20 mm, surfacing speed (Vn) – 7 and 10 m/h, frequency of fluctuations (N) – 18; 28; 32 and 45 min^{-1}; amplitude of fluctuations (A) – 25 and 40 mm. The tests were carried out on eight samples of S235JR steel of identical dimensions (Tab. I).

Process and results of the tests

The beginning and the section with the crater were cut off from the pad weld runs. Next, longitudinal and transverse macrospecimens were made from each pad weld run to determine the dimensions of runs, the degree of mixing γ and to study macro- and microstructure of runs. Dimensions of all tested runs, determined on transverse macrospecimens with an accuracy of 0.1 mm (average value of 5÷7 measurements) and degree of mixing are given in Table I.

The minimum degree of mixing at 37÷39% was found in samples 1 and 2, amount of penetration – 1.6÷1.7 mm. Smaller penetration – 1.4÷1.5 mm, found in samples 7 and 8, but the degree of mixing is 49÷50%.

The tests have shown that, according to the total assessment of the dimensions of pad weld runs and the degree of mixing, samples 2 surfaced at a speed of 7 m/h, fluctuation amplitude of A = 25 mm, and fluctuation frequency of N = 45 min^{-1} had the best indicators (see Tab. I).

Figures 1 and 2 present the macrostructure of longitudinal specimens of pad weld runs made at the speed of 7 and 10 m/h, with different frequency and amplitude of fluctuations. At a surfacing speed of 7 m/h, increasing the frequency of fluctuations in the electrode wire makes it possible to obtain a more even penetration and a more fluid line of padding weld penetration with the parent material (Fig. 1b and 1c). The most even penetration line is observed in sample 2, surfaced at fluctuation amplitude of 25 mm and a maximum frequency of 45 min^{-1} (Fig. 1b).
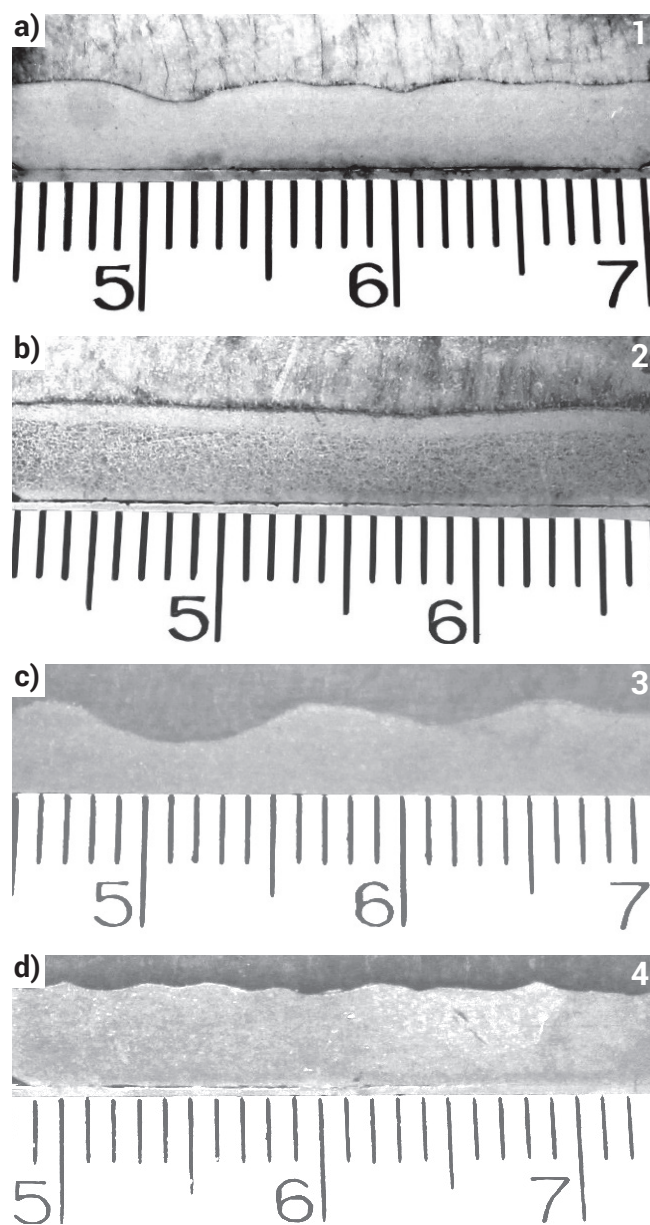

Fig. 1. Longitudinal macroscopic microsections of samples surfaced with speed of 7 m/h: a) sample 1: A = 25 mm; N = 28 min^{-1}; b) sample 2: A = 25 mm; N = 45 min^{-1}; c) sample 3: A = 40 mm; N = 18 min^{-1}; d) sample 4: A = 40 mm; N = 32 min^{-1}. Samples numeration – see Table I
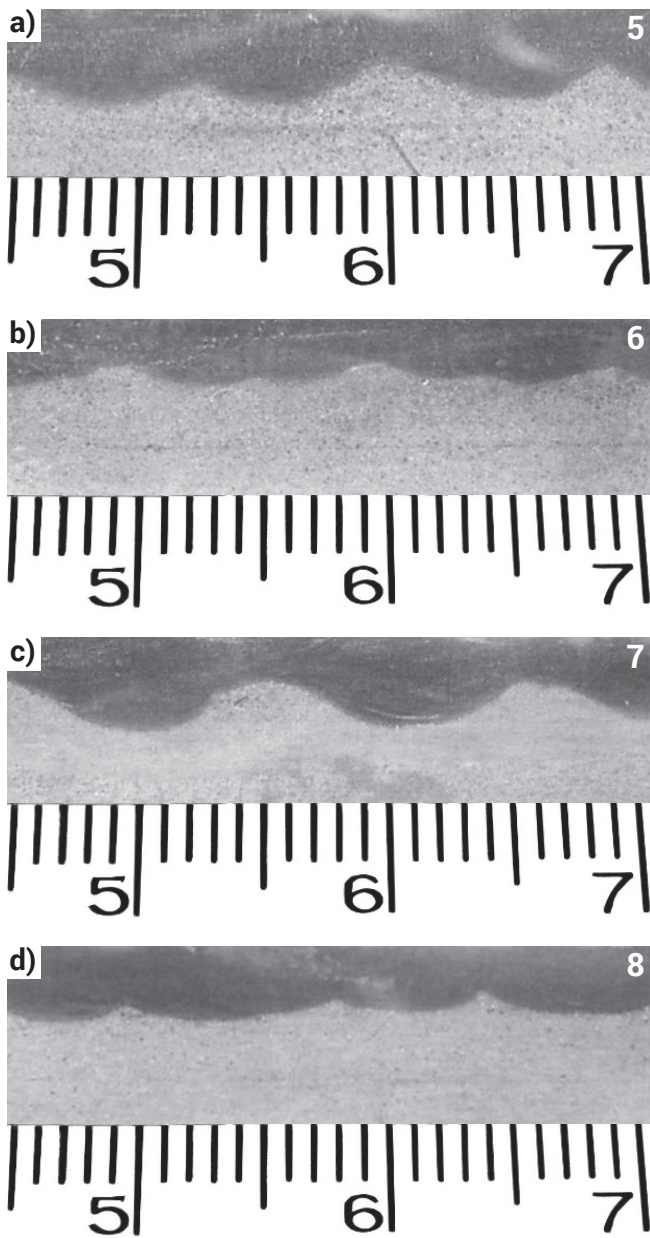
Fig. 2. Longitudinal macroscopic microsections of samples surfaced with speed of 10 m/h: a) sample 5: A=25 mm; N=28 min^{-1}; b) sample 6: A=25 mm; N=45 min^{-1}; c) sample 7: A=40 mm; N=18 min^{-1}; d) sample 8: A=40 mm; N=32 min^{-1}. Samples numeration − see Table I
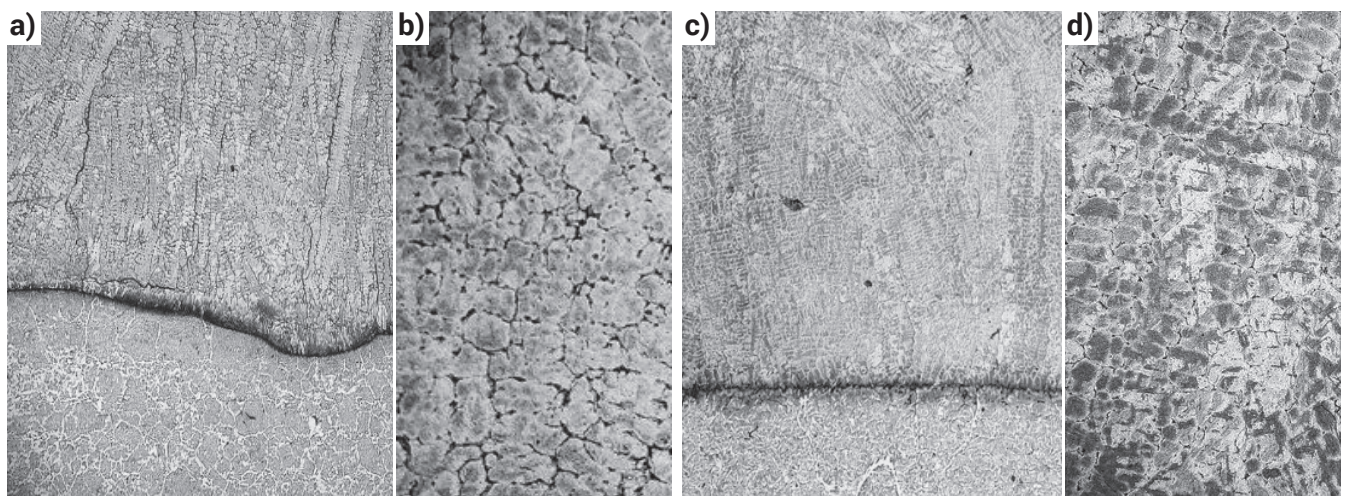
With an increase in the surfacing speed up to 10 m/h, an even penetration was not obtained at any frequency and amplitude of fluctuations in the electrode wire (Fig. 2a to 2d). At the same time, during the welding with increased speed (10 m/h), the increase in the frequency of electrode wire fluctuations also promotes a more even penetration and greater „smoothness" of the fusion line (Fig. 2b and 2c), however this effect is lower than at the surfacing speed of 7 m/h.

Investigation of the microstructure of the padding weld of sample no 1 (Vn = 7 m/h, A = 25 mm, N = 28 min^{-1}) showed that it has a dendritic structure (Fig. 3a). In the near-surface layers of padding weld a microstructure of cellular structure prevails, with an average grain diameter of 60÷80 μm. The hardness of the matrix material, determined by the Vickers method according to GOST 9450-76, is HV1 = 5420÷6060 MPa (martensite + carbides). The hardness of the matrix material, determined by the Vickers method according to GOST 9450-76, is HV1 = 5420÷6060 MPa (martensite + carbides).

At the crystallite boundary there is a precipitation of spherical carbide chains (Fig. 3b). The structure of the surfaced metal of sample no 2 (Vn = 7 m/h, A = 25 mm, N = 45 min^{-1}) − dendritic-cellular with a predominance of cellular (Fig. 3c), with a mean diameter of crystallites of 30÷40 μm. With the fusion line in the native material the structure becomes dendritic. The width of crystallites in this zone is 70÷90 μm. Hardness of the matrix material HV1 = 4880÷5480 MPa. At the crystallite boundaries, as well as in sample no 1, spherical finely dispersive carbides are released (Fig. 3d). The HAZ has a width of 3600 μm.

The microstructure of the padding weld metal of sample no 3 (Vn = 7 m/h, A = 40 mm, N = 18 min^{-1}) − dendritic-cellular with a cellular predominance on the surface (Fig. 4b). The average cell diameter is 50÷60 μm. Hardness of the matrix material − HV1 = 6060÷6130 MPa. A martensite band was observed at the fusion line from the padding weld side. Martensite in this zone is formed in the form of large needles. The width of crystallites at the fusion line is 70÷80 μm. Width of HAZ − 2100 μm.

The padding weld of sample no 4 (Vn = 7 m/h, A = 40 mm, N = 32 min^{-1}) also has a dendritic-cellular structure, with a cellular form predominance on the surface. Diameter of the cells is 40÷50 μm (Fig. 4b and 4d). At the fusion line − dendritic structure, the width of crystallites in this area is 60÷80 μm. The hardness of the crystalline matrix in a given area is lower than in sample No. 3 and is HV1 = 5140÷5420 MPa. Width of HAZ − 1800 μm.
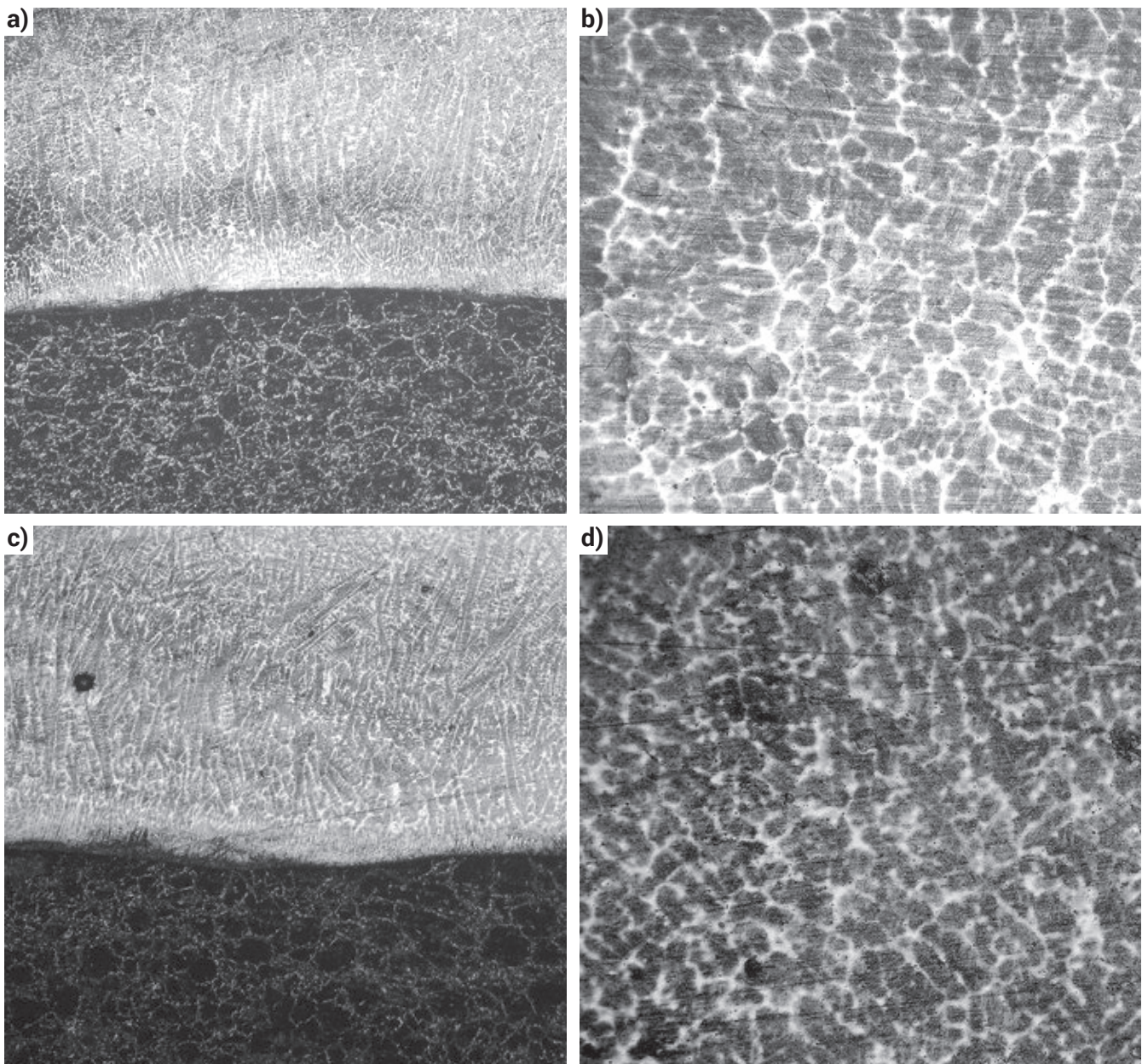

Fig. 3. Microstructure of padding weld samples 1 (a, b) and 2 (c, d): a, c − fusion penetration zone, x20; b, d − padding weld metal, x100. Electrolytic etching in chromic acid. U$_{xx}$=20 V; t=3÷5 s. Samples numeration − see Table I

Fig. 4. Microstructure of padding weld samples 3 (a, b) and 4 (c, d): a, c − fusion penetration zone, x20; b, d − padding weld metal, x100. Electrolytic etching in chromic acid. U_{xx}=20 V; t=3÷5 s. Samples numeration − see Table I

Examination of the microstructure of sample no 5 (A=25 mm, Vn=10 m/h, N=28 min^{-1}) showed that it has a dendritic structure (Fig. 5b). The cellular structure prevails in the near-surface layers of padding weld, with an average diameter of 60÷80 μm. The hardness of the matrix is HV1 6860 MPa (martensite). Diameter of the cells in the upper part of the padding weld is 15÷20 μm; width of crystallites h − 15÷25 μm, HAZ − 1200 μm.

The microstructure of the sample no 6 (Vn=10 m/h, A=25 mm, N=45 min^{-1}) are shown in figures 5c and 5d. It also has a dendritic structure with a cellular structure in the near-surface layers. Diameter of the cells − 25÷35 μm; width of crystallites h − 25÷50 μm, HAZ − 800÷900 μm. There are precipitations of intermetallic phases and carbides on the boundaries of crystallites and cells. Microhardness HV1 6810 MPa in a bright layer and HV1 6340 MPa in a dark layer.

Examination of the microstructure of sample no 7 (Vn=10 m/h, A=40 mm, N=18 min^{-1}) showed that it has a dendritic structure (Fig. 6a and b). Diameter of the cells − 40÷60 μm; Crystallite crystallite width − 40÷60 μm, HAZ − 1000÷1200 μm. Microhardness − HV1 6420 MPa. There are precipitations at the boundaries of crystallites and cells, but there are far fewer of them than in the samples shown in Figure 5.

The microstructure of the padding weld metal of the sample no 8 (Vn=10 m/h, A=40 mm, N=32 min^{-1}) is also dendritic-cellular (Fig. 6c and 6d). Diameter of the cells − 15÷30 μm; width of crystallites h − 30÷40 μm, HAZ − 600÷800 μm. The chemical and structural inhomogeneity of the 25H5FMS type alloy surfaced on S235JR steel was examined by microrentgenospectral analysis, X-ray diffraction analysis and metallographic analysis. The results of the microrentigeno-spectral analysis of the alloying elements showed that the width of the fusion zone with the base material (transition zone) decreases with the increase of the frequency of fluctuations (Tab. II). With a surfacing speed of 7 m/h, electrode wire fluctuation frequency N=28 min^{-1} and amplitude A=25 mm, the width of the transition zone is 35÷40 μm, and at N=45 min^{-1} − 20÷25 μm (Tab. II , samples 1÷4). At A=40 mm and frequencies N=18 min^{-1} and N=32 min^{-1}, the width of the transition zone is 30÷35 μm and 15÷20 μm.

In the fused zone there is a smooth change in concentration, the chemical heterogeneity of the weld metal is insignificant and amounts to Cr_{max}/Cr_{min}=1.23÷1.47 for chromium, and Mo_{max}/Mo_{min}=1.21÷1.31 for molybdenum. Increasing the frequency of fluctuations in the electrode wire favors obtaining
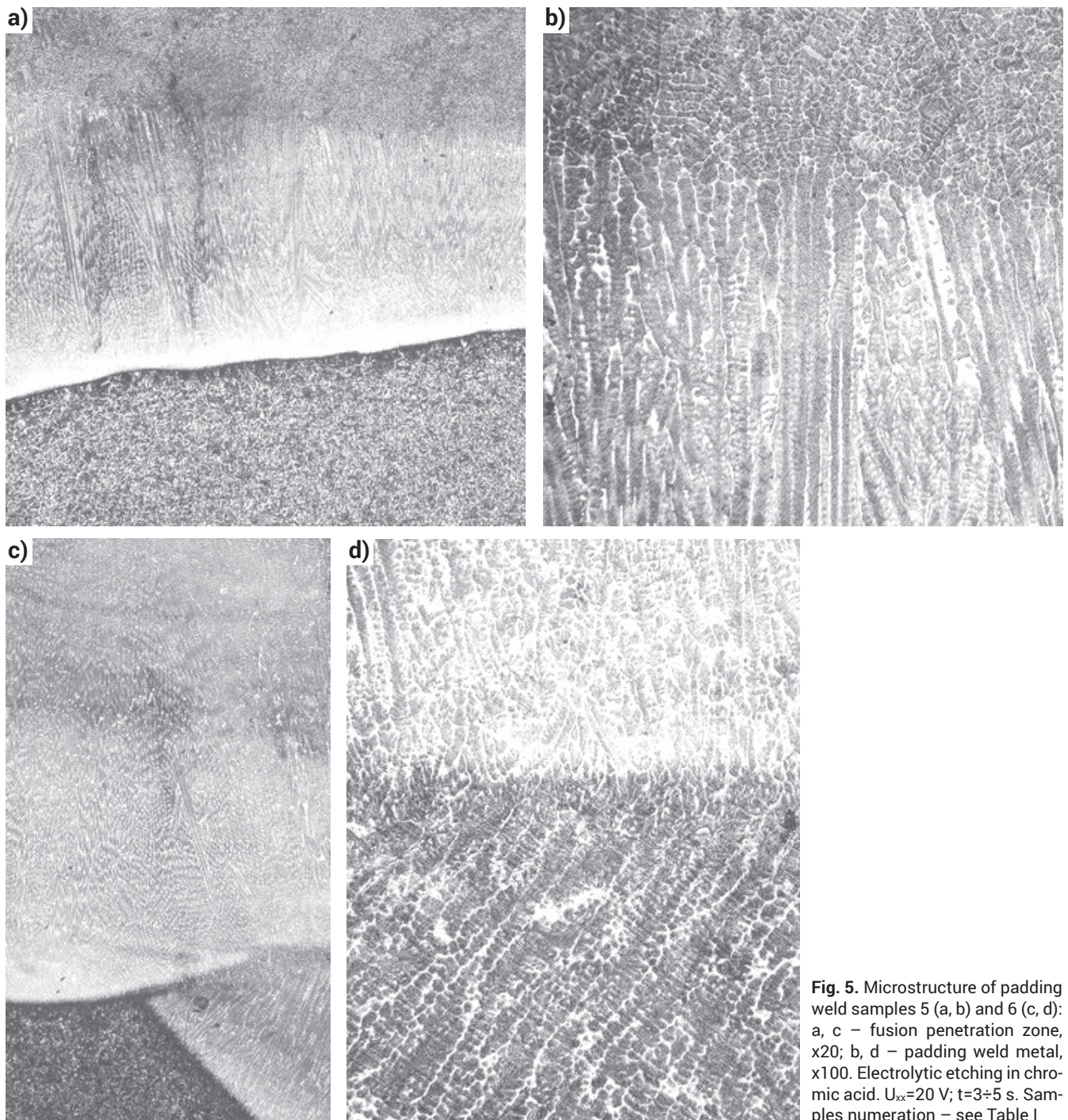
Fig. 5. Microstructure of padding weld samples 5 (a, b) and 6 (c, d): a, c − fusion penetration zone, x20; b, d − padding weld metal, x100. Electrolytic etching in chromic acid. U_{xx}=20 V; t=3÷5 s. Samples numeration − see Table I

Table II. Effect of oscillation electrode surfacing parameters on the microstructure and chemical inhomogeneity of samples 1÷8

| Sample no	Surfacing conditions			Microstructural state parameters			Indicators of chemical heterogeneity according to Cr and Mo	
	V_n, m/h	A, mm	N, min^{-1}	$d_{komórk}$, μm	Width of the transition zone, μm	Microhardness HV1, MPa	Cr_{max}/Cr_{min}	Mo_{max}/Mo_{min}
1	7	25	28	60÷80	35÷40	5420÷6060	4.5/3.4=1.32	0.32/0.25=1.28
2*	7	25	45	30÷40	20÷25	5420÷5480	4.8/3.9=1.23	0.40/0.33=1.21
3	7	40	18	50÷60	30÷35	6060÷6130	3.4/2.3=1.47	0.42/0.32=1.31
4	7	40	32	40÷50	15÷20	5140÷5400	3.1/2.2=1.41	0.35/0.28=1.25
5	10	25	28	25÷35	35÷40	6800	4.2/3.1=1.35	0.41/0.30=1.36
6	10	25	45	15÷20	20÷25	6700÷6800	4.6/3.2=1.44	0.38/0.30=1.26
7	10	40	18	40÷60	30÷35	6400÷6300	3.8/2.9=1.31	0.42/0.34=1.23
8	10	40	32	15÷30	15÷20	6340÷6810	3.5/2.4=1.46	0.34/0.28=1.21
Note: * − sample surfaced at the optimum settings of the technological parameters of the process was marked								
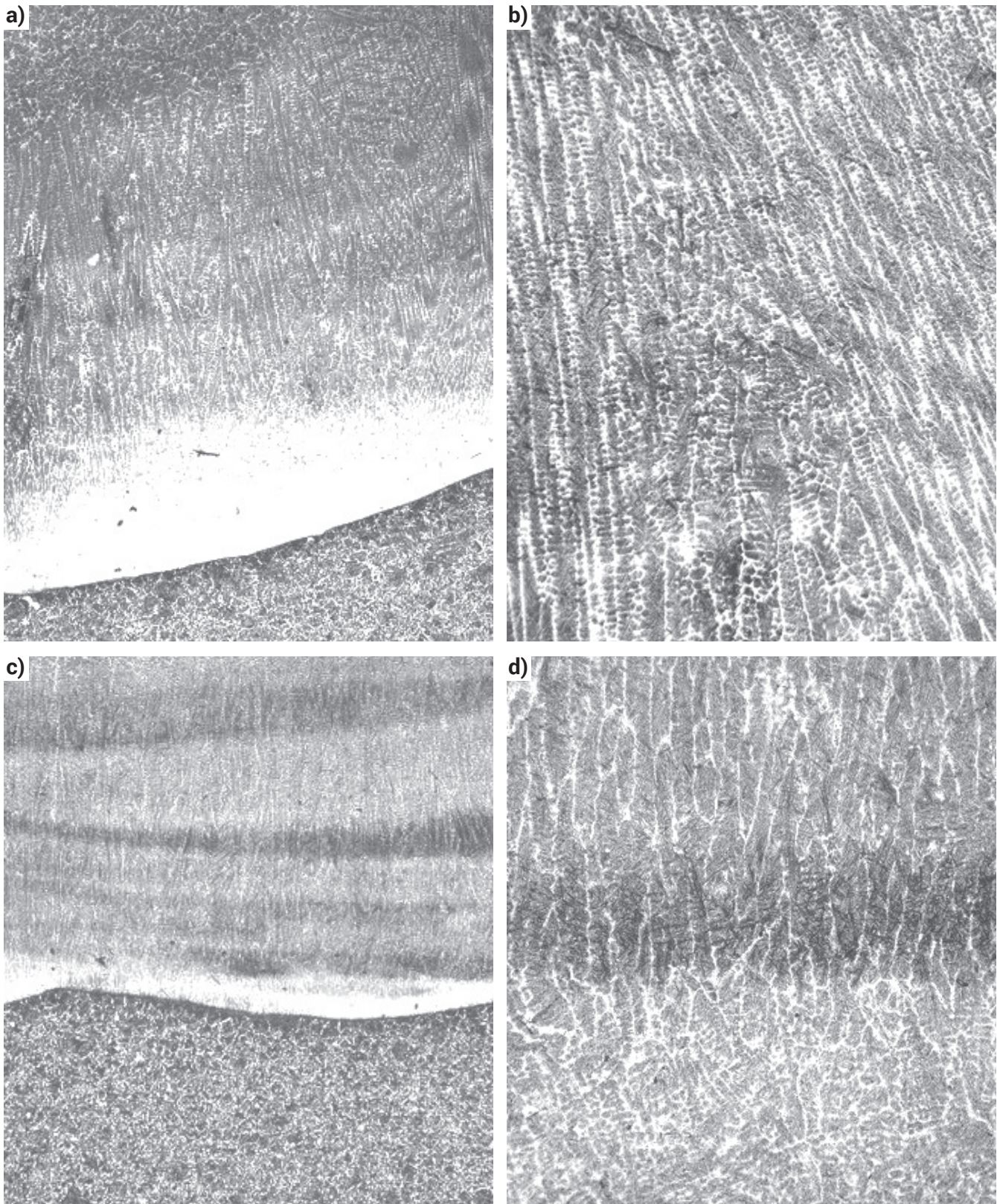
Fig. 6. Microstructure of padding weld samples 7 (a, b) and 8 (c, d): a, c – fusion penetration zone, x20; b, d – padding weld metal, x100. Electrolytic etching in chromic acid. Uxx=20 V; t=3÷5 s. Samples numeration – see Table I

a dispersive structure, a more even distribution of alloying elements, a more „smoothed" fusion line, as well as increasing the homogeneity of the chemical composition of the surfaced metal. The hardness of the matrix is 5140÷6060 MPa. In the surfaced samples, Cr_7C_3 and Fe_3C carbides, as well as intermetallic phases of the $Mo_5Cr_6Fe_{18}$ type were found.

With the increase of the surfacing speed to 10 m/h a similar relationship is observed (Tab. II, samples 5÷8). Increasing the frequency of fluctuations reduces the width of the transition zone, the chemical heterogeneity of the weld metal is $Cr_{max}/Cr_{min}=1.31÷1.46$ for chromium, and $Mo_{max}/Mo_{min}=1.21÷1.36$ for molybdenum. The matrix hardness in this case is slightly higher and amounts to 6340÷6810 MPa.

Conclusions

The tests carried out on the influence of the submerged arc surfacing with oscillating electrode on the padding weld properties have shown that as the frequency of fluctuations in the electrode wire increases, at the same amplitude of the oscillating movements and the surfacing speed:
– surfacing formation is improved;
– the homogeneity of the chemical composition of the surfaced metal increases, and the more dispersive structures are obtained;
– the width of the fusion zone with the parent material is reduced;
– a more even distribution of alloying components occurs;
– there is a more even penetration and „alignment" of the fusion zone of padding weld with the parent material.

It should be noted that these relationships practically do not change as the amplitude of fluctuations increases. Optimal parameters of padding weld forming, penetration depth and degree of mixing as well as structural and chemical homogeneity are ensured in test conditions at the frequency of electrode wire fluctuations of $N=45$ min^{-1}, amplitude $A=25$ mm and welding speed of $Vn=7$ m/h.

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