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X-Ray Structural Study of 09Nn2Si Steel Welded Joints

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Abstract. The article is devoted to handling a vital scientific and technical problem of improving operational reliability and safety of critical constructions, exploited in Siberia and Far North, by developing of new technological approaches to welding. In the article results of X-ray diffraction examinations of 09Mn2Si steel welded joints are given, produced by different welding operations. Resulting from researches, the authors have concluded that pulse-arc welding is the most preferred welding process as compared with direct current welding.

Introduction

It is known that production of cold-resistant welds of high strength steels is greatly hindered due to a number of specific factors. This is due, first of all, to arc burning when welding at low ambient temperatures, as well as to crystallization kinetics of the weld metal and to stresses and deformations in welded structures. Practice of exploitation of machines and constructions, employed in Siberia and Russia's Far North , has shown that performance of different types of machinery decreases in winter to 1.5 times if compared with a summer period. MTBF drops 2-3 times; an actual service life is reduced by 2-3 times as compared with a rated life [1].

Analysis of the data on failures of the equipment and structures operated at low temperatures shows that damages occur more frequently in welds as they have lower cold resistance if compared with the base metal [2]. Welding enhances grain growth, and further hydriding, which increases the cold cracking of welded joints. Furthermore, heat welding enhances phase transformations and secretion of impurities at grain boundaries, which also increases brittleness of steel [3]. It is known that cementite (iron carbide), as a phase component, occurs in the iron-carbon alloys even there is small carbon content [4]. In [5, 6] processes of carbide formation during thermal tempering of structural steels are examined.

It is shown that compositions of carbides, formed at various tempering temperatures of structural steels, are unstable. Carbides, generated at low and medium tempering temperature, contain less alloying elements than such carbides generated at higher tempering temperatures [5].

[6] shows a change in cementite volume fraction in 30CrNi3MoV cast steel, depending on tempering duration at 660^{o} C; it is noted that an increase in the cementite volume fraction occurs in the first minute of tempering. Thus, it can be assumed that secretion of cementite phases are possible

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when welding, even after brief exposure to temperatures; these could reduce the resistance to cracking in weld joints.

To solve the problem development of fundamentally new provisions of the welding theory is required, which in practical application of welding and surfacing will increase the operational reliability of welded structures and products for the North. The basis of these provisions, in our opinion, may be methods of adaptive control over complex electro-dynamic system: power supply - arc - weld pool – product, which provides conditions for formation of equal strength in zones of cold-resistant material joints through optimal heat input at welding [7,8].

In recent years, fundamental studies of welding processes and the nature of various defects when welding in the cold made it possible to establish physical nature of arc acting when welding at low temperatures [9]. This allowed developing a conceptual approach to reducing unsoundness and increasing strength and operational performance of welded joints stated in adaptive pulse arc welding method. It lies in the control over all stages of the formation of the welded joint: arc burning, melting, electrode metal transfer to the weld pool and weld metal crystallization through feedback channels that control the basic energy characteristics of the process, taking into account perturbing actions [7, 10]. This method became the basis of innovative technological solutions in welding and surfacing that increase the safety performance, survivability and operational reliability of technical systems operating in Siberia and the High North.

The purpose of the work is to develop concepts of properties of 09Mn2Si steel welded joints produced by DC arc welding or by pulse-arc welding at above-zero and sub-zero temperatures, performed by X-ray diffraction examination.

Research technique

Butt welds of 09Mn2Si steel were tested; welded samples according to State Standard 5264-80 were prepared for tests, connection of S17 type. Pre-welded plates with dimensions of 100x200x6 mm were lengthwise processed with a bevel angle of 30° and 2 mm dulling. Before welding the plates, for to avoid post-weld deformation, were assembled in a special jig with a clearance of 2.5 - 3.0 mm; tacks were arranged on the ends of the plates. One-side weld of sheet samples was performed in two runs, a root run and a facing run, with LB-52U electrodes. When welding the root run an electrode with diameter of 3.2 mm was used, and for the facing run – that of 4 mm.

The electrodes are certified by NAWC (National Association of Welding Control) and are widely used to weld various low-carbon and low-alloy steel constructions. Carbon content in LB-52U electrode wire is equal to carbon content in 09Mn2Si steel (Table 1).

Table 1. Chemical content (%)

Ø, mm	**C**	**Si**	**Mn**	**P**	**S**	**Ni***	**Cr***	**Mo***	**V***
3.2	0.06	0.51	1.02	0.011	0.006	0.01	0.02	0.01	trace
4.0	0.06	0.49	1.01	0.013	0.004	0.01	0.03	0.01	trace

* These elements are not added on purpose.

Welding of the samples was made with the inverter power supply FEB-315 «MAGMA» with modes available for DC welding and adaptive pulse-arc welding. Temperature conditions of ambient air were changed from +18°C, up to -48^{o}C.Registration of welding parameters was performed using the device AWR-224 MD.

The average parameters of welding conditions are shown in Tables 2 and 3.

X-ray diffraction examinations were performed with a high-precision X-ray diffractometer ULTIMA IV Rigaku, using Co-κ_α radiation. The diffractograms were obtained from etched side surfaces of the samples. 4 samples of 09Mn2S steel welds were examined:

- №1 - modulated current welding at + 18°C;
- №2 - DC welding at + 18°C;

- №3 - modulated current welding at -48°C;
- №4 - DC welding at -48°C

X-ray exposure of the samples was performed in three areas: №1 - metal joint (MJ); №2 - at a distance of 1.5 mm from the fusion line; №3 - at a distance of 15 mm from the fusion line (see Figure 1). The results were compared with the reference diffractogram obtained by X-ray exposure of the annealed sample of the 09Mn2Si steel.

The first series of surveys was made in the angle range $42.00^o \leq 2\theta \leq 162.00^o$ at a scanning speed of 1 deg/min and scan step 0.02^o with the aim of finding all peaks obtained from the sample. The second series of surveys was made in the angle range $50.00^o \leq 2\theta \leq 58.00^o$ at a speed of 0.1 deg/min and step scan 0.01^o for more exact definition of the line of cementite (121) and the peak heights.

Table 2. Modes of DC arc welding

Run	I, A	U, B	$V_{св}$, m/h	Heat input, kJ / m
Root	90	25	4,9	1405
Facing	150	25	6,99	1642

Table 3. Modes of adaptive pulse-arc welding

Run	$I_и$, A	$I_п$, A	$t_и$, c	$t_п$, c	U, B	$V_{св}$, m/h	Heat input, kJ / m
Root	90	40	0,3	0,3	20	4,29	1017
Facing	180	50	0,3	0,3	24	6	1606

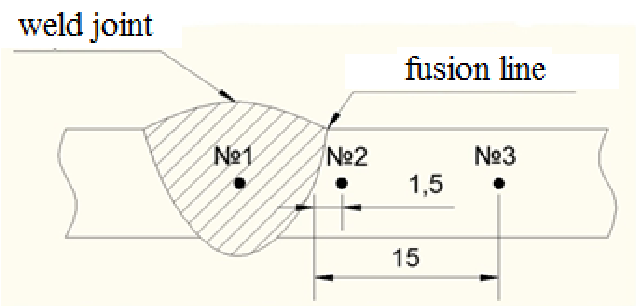

Figure 1. Diagram of X-ray exposure of samples and numbers of areas

Results and discussion

It is known that sensitivity of the X-ray examination is often insufficient for qualitative and quantitative determination of cementite in low-alloy steels. This statement is confirmed by the diffraction pattern shown in Figure 2. Steel 09Mn2Si refers to ferrite-pearlite class, but X-ray examination of the samples in the initial state does not show the presence of cementite phases. Obviously, sensitivity of the diffractometer is insufficient to identify a low content of cementite phase in the steel.

During welding, re-melting of welded material and its subsequent crystallization occurs with formation of zones of structural heterogeneity. Behavior of the material in this zone during operation determines the properties of permanent joints, especially if thermal-strength loading.

Study of the weld metal and heat affected zone of welded joints of steel, obtained at different welding modes, revealed significant differences in the diffraction patterns of the metal. Evidently, change in the welding thermal cycle facilitates quantitative growth of cementite phases; the percentage of which can be estimated by X-ray examination.

X-ray phase analysis is based on the fact that each phase has a specific crystal lattice with certain parameters and the corresponding system of lines on the radiograph. Therefore, in general, when

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radiographing of the metal, which is a mixture of several phases, a radiograph is obtained, which contains all lines of the phases forming the sample [6].

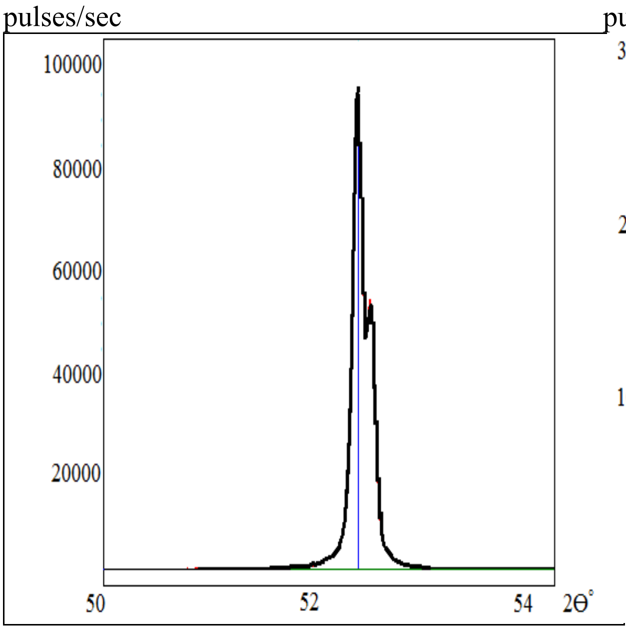

Figure 2. The XRD pattern of reference sample

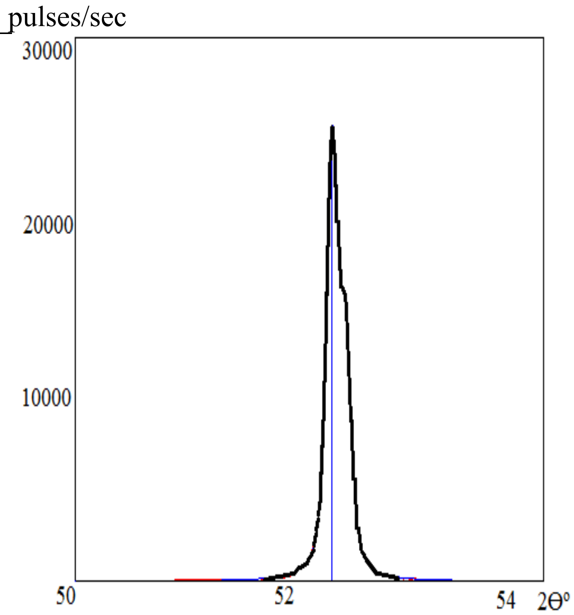

Figure 3. XRD pattern of area №3, sample №1

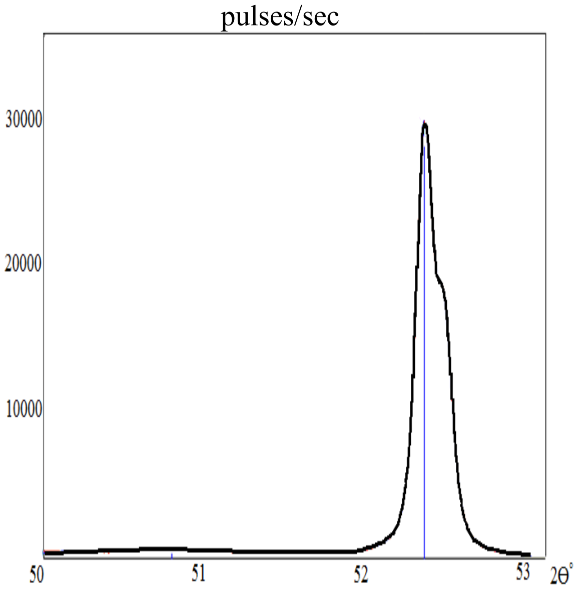

Figure 4. XRD pattern of the sample №2 weld metal

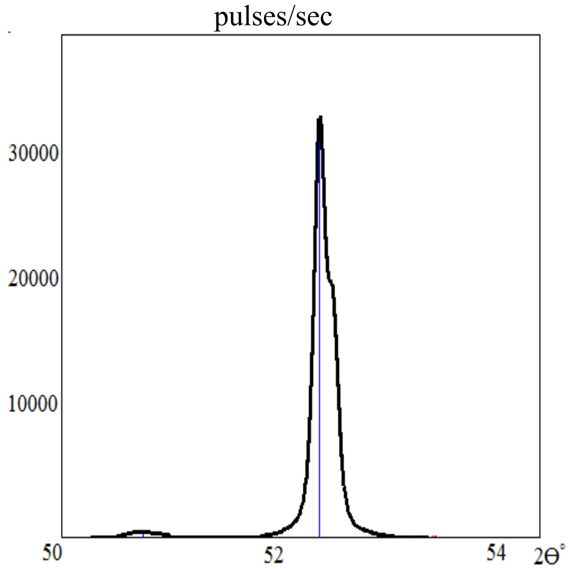

Figure 5. XRD pattern of the sample №4 weld metal

Intensity of different phase lines on radiographs depends on many factors, including quantity of a particular phase. With increase of phase content in the mixture, intensity of the lines, corresponding to it, increases. However, a reliable quantifying of a particular phase in a mixture is possible only if there are certain minimum quantities of it. Further reducing the amount of this phase will lead to almost complete disappearance of its lines on radiographs [11].

X-ray diffraction results are shown in Table 4, where θ - angle of reflection; I - intensity of diffraction lines from the reflection plane (121) and (110). In the reference sample there are no cementite lines (Fig. 2), and in the welds there are lines of cementite (iron carbide - Fe_3C), except section 3 of the sample1 (Figure 3).

For analysis, X-ray diffraction examination of the samples welded with different welding methods at above-zero and sub-zero temperatures was carried out (see Table 3). Analysis of the cementite diffraction lines showed that the highest intensity (and thus content) is found in the weld metal, area 1 (Fig. 1), and the smallest in area 3 at a distance of 15 mm from the fusion line (Fig. 1). Figures 4 and 5 show the diffraction patterns of the weld metal samples № 2 and № 4. Depending on the welding conditions the intensity of cementite lines changes. Thus, the DC welds (samples № 2 and № 4), show larger intensity than the pulse-arc welds (samples № 1 and № 3).

It was found that increasing of the cementite line intensity during welding at sub-zero temperatures as compared with welding at above-zero temperatures. As it is known, cementite is a brittle substance, and its high content in the steel reduces cold resistance. Table 4, column 7, shows the percentage of iron and cementite line intensities where the greatest value (1.4%) was found in the weld metal produced by DC welding at above-zero temperature.

Table 4. The results of X-ray diffraction study

Sample	№ area	2θ Fe_3C (121) [deg]	I Fe_3C (121) [cps]	2θ α-Fe (110) [deg]	I α-Fe (110) [cps]	% Fe_3C (121) от α-Fe (110)
1	2	3	4	5	6	7
№1	1	50.78	164	52.32	25380	0.65
	2	50.89	131	52.33	25151	0.52
	3	-	-	52.33	24424	-
№2	1	50.79	398	53.34	28574	1.4
	2	50.70	230	52.34	27908	0.82
	3	51.12	66	52.33	26945	0.24
№3	1	50.67	222	52.33	25171	0.88
	2	50.86	103	52.34	25309	0.41
	3	50.94	44	52.34	25737	0.17
№4	1	50.73	289	52.32	31427	0.92
	2	50.89	283	52.33	25120	1.13
	3	51.15	106	52.34	25469	0.42
Reference sample		-	-	52.36	91391	-

Conclusion

The study has established that in 09Mn2Si steel welded joints, in areas of weld metal and heat affected zone, iron carbides increase noticeably; their content is entirely dependent on the methods and welding conditions as well as temperature conditions of formation of welded joints.

In general, the use of adaptive pulse-arc welding enables to reduce the content of cementite in the joints welded at above-zero and sub-zero temperatures; that demonstrates advantages of these methods for welding ferritic-pearlitic steel structures if compared with methods of DC welding.

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References

[1] Larionov V P Arc welding structures for northern *Nauka* Novosibirsk 1986
[2] Golikov N I Ammosov A P The strength of welded joints of tanks and pipelines operated in the North *NEFU* Yakutsk 2012 p 232
[3] Makarova E L (Ed) Welding and welding materials, walkability of materials *Metallurgy* 1991 Vol. 1 p 528
[4] Kalinin B D Rudnev A V The effects of diffraction X-ray fluorescence analysis and their use for analytical purposes *Analysis and control* 2011 15(3) p 332-338
[5] Tihonkova O V Popova N A Tsellermaer V V Gromov V E Kozlov E V Influence of tempering on the phase composition of cast steel structural intermediate-alloy steel *Proceedings of the higher educational institutions Iron and steel* 2007 p 52-56
[6] Mirkin L I X-ray inspection of engineering materials *Mechanical Engineering* Moscow 1979
[7] Saraev Y N Adaptive pulse-arc mechanized welding in the construction of main pipelines *Welding production* 2002 No 1 p 4-11
[8] Saraev Y N Sleptsov O I Bezborodov V P Nikonova I V Tyutev A V Fatigue failure and properties of welded joints of pipelines in Siberia and the Far North *Mounting and special works in construction* 2005 No 8 p 18-22
[9] Saraev Yu N Bezborodov V P Grigorieva A A Golikov N I Dmitriev V V and Sannikov I I Distribution of residual stresses in welded joints in 09G2S steel produced by adaptive pulsed-arc welding *Welding International* 2015 Vol. 29 No. 2 p 131–134 http://dx.doi.org/10.1080/09507116.2014.897804
[10] Lvov N S Gladkov E A Automation and automation of welding processes *Mechanical Engineering* Moscow 1982 p 302
[11] Umansky Y S Radiography of metals and semiconductors *Metallurgy* Moscow 1969 p 496