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AUTOMATIC SUBMERGED-ARC WELDING OF BRIDGE SPANS OF HIGH-QUALITY STEELS 10KhSNDA AND 15KhSNDA IN FIELD

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Presented are the results of optimization of technology of automatic submerged-arc welding performed in assembly at construction of bridge spans of steels 10KhSNDA and 15KhSNDA (TU 14-1-5120–2008) under conditions of West-Siberian region. Taking into account local climatic and temperature conditions, the designations of metal structures, principle of steel alloying and thickness of welded sheets it is determined that welding shall be carried out using the modes providing heat input in the limits of 30-35 thou J/cm in two passes, on glass substrate with reduced by 20–30 % height of filling of metal-chemical filler. Necessary toughness and strength of welded joints on this technology is explained by favorable conditions for phase transformations and formation of homogeneous structure in weld metal and HAZ. 9 Ref., 4 Tables, 3 Figures.

Keywords: *bridge structures, automatic submerged-arc welding, heat input, fusion zone, embrittlement*

10KhSND, 15KhSND (GOST 6713–91) steel grades and 10KhSNDA and 15KhSNDA (TU 14-1-5120–2008) grades are used as a main material for manufacture of bridge structures of North implementation according to [1]. The main difference of steel produced by TU from standard ones is presence in their content of strong carbide-forming elements and somewhat decreased content of carbon, manganese, chromium, nickel and detrimental impurities (Tables 1 and 2).

The first experience of application of these steel grades, produced still by TU 14-1-5120–91, showed [2, 3] that butt welded joints of 12–16 mm thickness, received by one-sided single- and two-pass submerged-arc welding using metal-chemical filler (MCF) and copper forming substrates are susceptible to low-temperature embrittlement, particularly along fusion zone.

In new TU [4] chemical composition is corrected to the side of reduction of carbon equivalent. However, elimination of increased sensitivity of field welded joints to low-temperature embrittlement in single-pass automatic submerged-arc welding was not successful [5]. Therefore, present work is dedicated to optimization of automatic submerged-arc welding necessary for construction of bridge spans of steels 10KhSNDA and 15KhSNDA (TU 14-1-5210–2008) under temperature conditions of a region.

Materials and investigation procedure. Following the requirements of design documentation for construction of bridges of North implementation the rolled plates of category 2 and 3 in normalized or thermally improved state after quenching and high-temperature tempering with carbon equivalent value not more than 0.45 %, determined by formula [4], were used in the work.

Welding of long-length longitudinal and transverse joints of flooring of orthotropic and back plates of 12 mm thickness without groove preparation using MCF on copper and glass substrates was carried out under conditions of Mostootryad-96 in different time of the year. Flux AN-47 in combination with wire Sv-

Table 1. Chemical composition, wt.%

Steel grade	C	Si	Mn	Cr	Ni	Cu	Nb
10KhSND	< 0.12	0.8–1.1	0.5–0.8	0.6–0.9	0.5–0.8	0.4–0.6	–
15KhSND	0.12–0.18	0.4–0.7	0.4–0.7	0.6–0.9	0.3–0.6	0.2–0.4	–
10KhSNDA	< 0.12	0.8–1.1	0.65–0.95	0.3–0.6	0.2–0.5	0.4–0.6	0.03–0.06
15KhSNDA	0.1–0.15	0.4–0.7	0.6–0.9	0.3–0.6	0.2–0.5	0.2–0.4	0.03–0.06

Note. Amount of sulfur and phosphorus in steels 10KhSND and 15KhSND not more than 0.035 wt.%. Amount of sulfur in steels 10KhSNDA and 15KhSNDA not more than 0.010 wt.%, phosphorus — 0.015 wt.%. Replacement of niobium by vanadium in the amount 0.08–0.12 wt.% is allowed.

Table 2. Mechanical properties of steel

Steel grade	Ultimate strength σ_t, MPa	Yield limit σ_y, MPa	Relative elongation δ_s	Impact toughness *KCU*, J/cm^2 for rolled metal of categories at temperature, °C		
				1	2	3
				–40	–60	–70
10KhSND	530–670	390	19	29	29	29
15KhSND	490–670	335–345	19–21	29	29	29
10KhSNDA	510–670	390–495	19	29	29	29
15KhSNDA	470–685	335–450	19–21	29	29	29

10NMA of 4 mm diameter on the modes necessary for practical purposes were used for welding.

A quality control of welded joints was carried out systematically in the process of welding performance using destructive and non-destructive methods for detection of external and internal defects and determination of mechanical properties. The samples were made with the help of run-on plates, used for welding mode adjustment. In a series of cases for specification of received data the samples were manufactured directly from regular welded joints.

The samples of XIII type of GOST 6996–66 were subjected to static tension on rupture-test hydraulic machine. Impact toughness at normal and reduced temperatures were determined on samples of VI type on GOST 6996–66. Structure of weld metal and near-weld zone (NWZ) were examined applying optical microscope Neophot 32 at up to 500 magnification. Phase composition, fine structure, qualitative and quantitative analyses of morphological and structural constituents of austenite decay products in NWZ metal and fusion zone were examined using X-ray images on difractometer DRON-2.0, transmission electron microscopy applying diffraction light- and dark-field image.

Results and their discussion. It is determined that welded joints of orthotropic plates of steel 10KhSNDA and 15KhSNDA produced by single- and two-pass automatic submerged-arc welding with MCF on copper forming substrates have necessary strength and ductile properties, which lie at the level of base metal properties (Figure 1). At the same time these welded joints received by single-pass submerged-arc welding under summer as well as winter conditions at heat input more than 50 thou J/cm was found to be sensitive to low-temperature embrittlement, in particular, in a fusion zone. To a greater degree the embrittlement at –60 °C was observed in welding under winter conditions at environment temperature –15–20 °C using copper forming substrates (Table 3, variants 1, 3). Application of multipass automatic submerged-arc welding at reduced heat input using steel substrates with inserted strips of sheet glass on GOST 111–2014 of 4–5 mm thickness provides formation of quality welded joints in welding under summer as well as winter conditions (Table 3, variants 2 and 4).

The experience shows that welding with increased heat input on copper substrates results in boiling of molten metal with its further splashing through slag crust, pore appearance, overlaps and other weld defects.

Investigations of structure of samples cut out directly from standard butt joints determined that automatic submerged-arc welding of these steels at increased heat input (Table 3, variants 1 and 3) provokes formation in NWZ of coarse grain with fine plates of α-phase. The latter penetrate the grains with the products of intermediate austenite decay that indicates presence of intense overheating which resulted in formation of unfavorable Widmanstatten pattern (Figure 2).

In fusion zone period of α-phase lattice is more than in ferrite included in base metal structure. Scalar

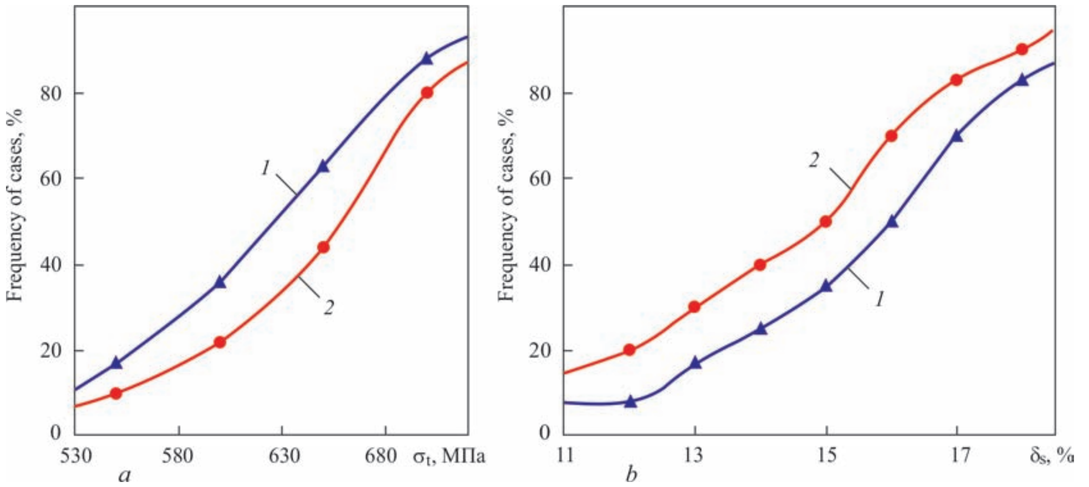

Figure 1. Frequency curves of distribution of ultimate tensile strength (*a*) and relative elongation (*b*) of welded joints of steel 10KhSNDA (*1*) and 15KhSNDA (*2*)

Table 3. Impact toughness of metal of single- and two-pass butt welded joints of steels

Number of variant	Steel grade of welded joint	Wall thickness of butt joint, mm	Number of passes	Average value of welding heat input of pass, J/cm	Average value of time of metal staying at temperature more than 1300 °C, s	Impact toughness *KCU* at –60 °C, J/cm^2		
						Base metal	Weld metal	Fusion zone
1	10KhSND	12	1	63 000	56.0	90...110	35...50	15...25
2	15KhSND	12	2	45 000 40 000	28.5 24.0	90...110	55...70	40...50
3	10KhSNDA	12	1	63 500	57.0	80...100	35...40	10...15
4	15KhSNDA	12	2	44 000 40 000	28.0 24.0	80...100	50...60	35...45

Note. In numerator heat input and time of staying of metal of first pass, in denominator — second.

density of defects of crystalline structure is at the level of scalar density of defects of crystalline structure of martensite α-phase forming in austenite decay in the field of martensite transformation (Table 4). There are coarse as well as fine carbides of mainly lamellar shape (Figure 3) in the joints, inside the grains and on boundaries of ferrite crystals. Amplitude of torsion curvature of crystal lattice reaches 950–1000 cm^{-1} and by its value approximates to the maximum value marked as martensite α-phase (Table 4).

It is determined that no Widmanstatten pattern was present in multilayer welding at reduced heat input (Table 3, variants 2 and 4) using glass substrate. Ferrite-pearlite structure with grain numbers 6 and 5 on GOST 5640–68 was formed in NWZ. Ferrite α-phase has significantly smaller period of its crystal lattice in comparison with α-phase formed in welding at increased heat input (Table 4). The scalar density of defects of crystalline structure lies in the limits of scalar density of defects of crystalline structure in proeutectoid ferrite of base metal of category 2 rolled stock delivered after normalizing. No carbides were observed in the crystal field and along α-phase boundaries.

Additional prove of data received from electron microscopy on presence of carbide and carbonitride inclusions in the fusion zone can be the results of microchemical analysis made on «MAR-1» device (X-ray microanalyser) on a procedure proposed in work [6]. The phosphorescent flashes were clearly registered in the samples received in one-sided single-pass automatic submerged-arc welding with increased heat input at electron beam passing along the fusion zone when carbide and carbonitride inclusions of niobium, vanadium and other carbide-forming elements included in 10KhSNDA and 15KhSNDA steel composition enter the electron beam. In microchemical analysis of the samples welded by multilayer welding with reduced heat input, amount of phosphorescent splashes rapidly decreased when carbide and carbonitride inclusions entered the electron beam. Their amount in fusion zone does not exceed similar indices in the base metal.

Received data as well as data stated in work [2] allowed making a conclusion that welding with increased (above 50 thou J/cm) heat input of 10KhSNDA and 15KhSNDA steels, microalloyed with strong carbide-forming elements, results in long-term stay of weld metal and NWZ in the field of high (above 1300 °C) temperatures. This provokes more complete solution of carbides and carbonitrides in liquid phase and austenite, austenite grain growth. Further cooling promotes formation of unfavorable Widmanstatten pattern, precipitation from austenite and melt of carbonitrides of vanadium, niobium and chromium, which in opinion of [7, 8] promote local distortion of crystal lattice of α-phase, reduction of dislocation mobility, in particular at negative temperatures and, as a result, complication of sliding process in deformation.

Thus, the main reason of low impact load resistance at negative temperatures of welded joints of bridge structures from steels 10KhSNDA and 15KhSNDA, received by one-sided automatic submerged-arc

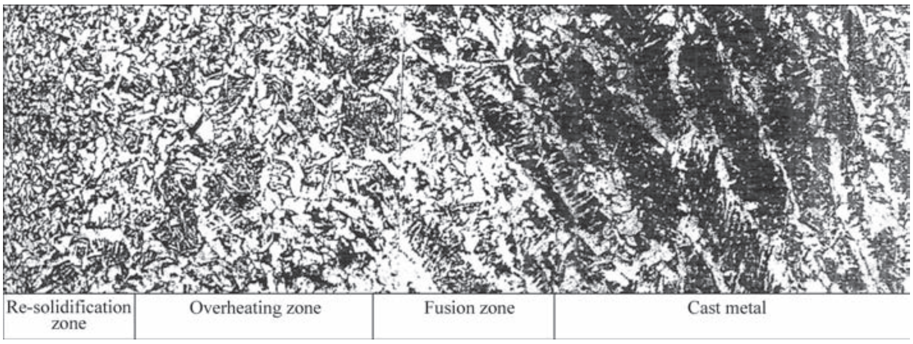

Figure 2. Microstructure (×250) of weld of steel 15KhSNDA produced by one-sided single-pass automatic submerged-arc welding at increased heat input (Table 3, variant 3)

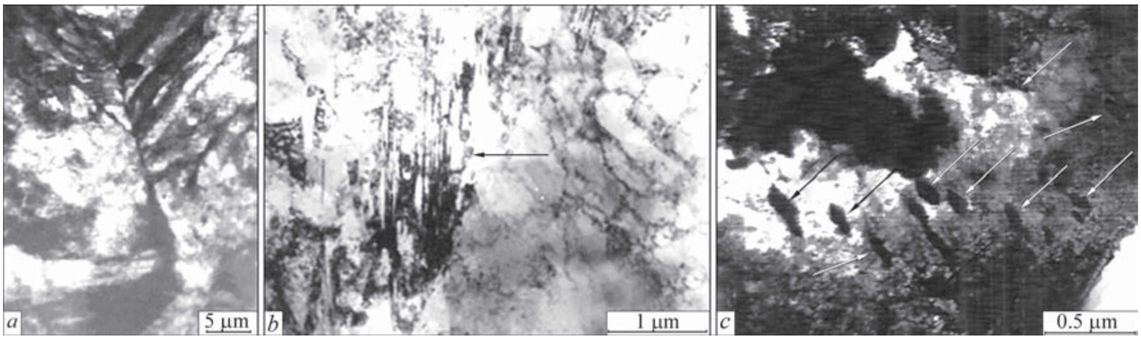

Figure 3. Fine structure in local areas of fusion zone of welded joint from steel 15KhSNDA: *a* — fragment of fusion line; *b* — accumulations of lamellar shape carbides; *c* — plates of α-phase with unidirectional carbide particles (indicated by arrows)

Table 4. Physical characteristics of α-phase

Designation	Period of crystal lattice, nm	Scalar density of dislocations ρ, 10^9, cm^{-2}	Amplitude of torsion curvature of crystal lattice, cm^{-1}
Table value for α-phase Fe [6]	0.28664	–	–
Steel 15KhSNDA in normalized state	0.28720	1.55–2.15	450–550
Martensite α-phase	0.28860	6.40–7.60	1350–1400
Welded joint (fusion zone). Table 3, variant 1	0.28770	5.60–6.70	950–1000
Welded joint (fusion zone). Table 3, variant 2	0.28735	2.10–3.20	560–640

Note. Accuracy of determination of lattice period ± 0.00005 nm, scalar dislocation density ± $0.2 \cdot 10^9$ cm^{-2}, torsion curvature of crystal lattice 50 cm^{-1}.

welding using solid wire with granulated filler at increased (above 50 thou J/cm) heat input applying copper forming substrates shall be considered a very nonuniform structure formed in fusion zone, which consists of dislocated ferrite saturated with carbide and carbonitride inclusions. They serve original stress concentrators promoting joint embrittlement. Authors of work [9] prove the appropriateness of application of glass substrate in automatic submerged-arc welding of steel bridge structures.

In the conclusion it can be noted that present results and earlier experience of performance of welding works under extreme climatic conditions of West Siberia requires optimizing the commercial conditions of automatic submerged-arc welding in the field. It is turned into welding in two passes at reduced heat input and application of glass substrates. At that, as a rule, the first pass in carried out with 30–35 thou J/cm input energy at 20–30 % reduced height of grit filling that provides ensured root weld penetration. The second pass, at 12–14 mm thickness of edges being welded forms more «accurate» on height weld since the first pass does not fill the whole gap volume. Welding on glass substrates reduces the cooling rate of the weld in the area of temperatures of phase transformations. This prevents formation of intermediate (bainite) and quenching structures. Welding works under autumn-winter conditions require particular control of preheating temperature and welding on preheated steel substrates with inserted glass strips of 4–5 mm thickness in their slots. Taking into account local climatic conditions and peculiarities of structure of bridge span in order to get quality welded joints at each new object it is necessary perform thoughtful adjustment of technology of automatic submerged-arc welding and apply for this so called technological probes delivered to construction site together with metal structures.

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