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INFLUENCE OF WELDING WIRE COMPOSITION ON WELD QUALITY IN WELDED JOINTS OF DISSIMILAR STEELS IN GAS-SHIELDED MECHANIZED WELDING

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For welding of dissimilar joints, the high-alloy welding materials are widely used. It is shown that the use of shielded arc mechanized welding method of dissimilar austenitic and pearlitic steels is limited due to formation of defects in the austenitic multilayer weld, such as lacks of fusion and lacks of penetration caused by appearance of a refractory oxide crust on the deposited metal surface. It is possible to increase the weld quality by providing its self-separation from the metal surface in the process of cooling. This is achieved by presence of a high content of such elements as silicon, titanium, zirconium, etc. in the welding wire, which reduce the amount of spinels based on chromium, nickel, molybdenum and others in the composition of oxide crust and increase the amount of brittle glassy phase. 15 Ref., 3 Tables, 1 Figure.

Keywords: *welding wire composition, mechanized arc welding, shielding gas, dissimilar steels, oxide crust, self-separation of crust*

A characteristic feature of modern technologies for welding dissimilar steels is the application of predominantly manual arc welding using high-nickel materials even for joining pipe elements such as branch pipes, bends, T-bends, etc., which are usually produced by mechanized welding. The high content of nickel in the composition of welding materials is predetermined by the need in reducing the thickness of a martensitic interlayer and diffusion of carbon in the fusion zone of austenitic weld with pearlitic steel [1, 2]. However, the instability of weld formation, characteristic for manual arc welding, leads to increase in chemical heterogeneity and decrease in the influence of nickel on structural heterogeneity in the fusion zone of dissimilar steels and promotes the formation of cracks in this zone. One of the main causes for limiting the application of mechanized welding of dissimilar steels in shielding gas is the formation of defects in the austenitic multilayer weld such as lacks of fusion and lacks of penetration due to the presence of refractory oxide crust on the deposited metal surface [3, 4]. At the same time, it was established that during application of CO_2 in its mixture with oxygen or with nitrogen as a shielding gas, the chemical and structural heterogeneity decreases [5, 6], and also the resistance to pore formation in this zone increases [7, 8]. This is facilitated both by increase in the level of austenite content in metal as well as improvement in the fluidity of metal in the weld pool and, in particular, in the near-wall area [9].

The successful use of mechanized welding of dissimilar steels is known in using carbon dioxide or its mixture with nitrogen or air as a shielding gas [10]. The absence of defects in the weld was obtained due to application of welding high-alloy wire of the composition 08Kh20N9G7T, during welding of which the formed oxide crust is independently separated from the surface of the deposited metal in the process of cooling. Consequently, during welding in an oxygen-containing shielding gas, it is possible to produce a defect-free austenitic weld and here the selection of the composition of welding wire is very important.

The aim of this work is determination of basic principles of selecting the composition of welding austenitic wire to prevent the formation of defects in the austenitic weld during mechanized welding of dissimilar steels in shielding gas.

The work was carried out by analyzing the chemical composition of the known high-alloy welding wires with different nickel content relative to the probability of self-separation of oxide crust from the surface of deposited metal. The results were checked by producing welds using mechanized welding in the mixture of CO_2 with 2 % nitrogen with evaluation of their quality. At the same time, the separation, chemical composition and glass transition temperature of oxide crust as well as crystallization temperature of the weld metal were determined by high-temperature thermal analysis using the installation VDTA-8M.

The fundamental principles for selecting chemical composition of welding wires for welding of dissim-

Table 1. Grade composition of welding wires recommended for welding of dissimilar steels, mass.%

Grade (alloying type) of wire, standard document	C, not more	Si	Mn	Cr	Ni	Mo	Ti	S	P
								Not more	
Sv- 08Kh20N9G7T, GOST 2246–70	0.10	0.5–1.0	5.0–8.0	18.5–22.0	8.0–10.0	–	0.6–0.9	0.018	0.035
EP 622 (Kh25N25M3G2), TU 14-1-4968–91	0.08	≤0.40	1.2–2.0	23.5–26.5	23.5–26.5	2.5–4.0	–	0.015	0.020
EP 673 (Kh25N40M7G2), TU 14-1-4968–91	0.08	≤0.40	1.2–2.0	23.5–26.5	38.5–41.5	6.6–8.0	–	0.015	0.020
EP 606 (Kh25N60M10G2), TU 14-1-4968–91	0.10	≤0.40	1.0–2.0	23.5–26.5	58.5–61.5	9.0–11.0	–	0.01	0.015

Table 2. Chemical composition of oxide crust on the weld surface in the mixture of CO_2 with nitrogen, mass.%

Type of wire alloying	SiO_2	MnO	Cr_2O_3	MoO_3	Fe_2O_3	TiO_2
Kh25N25M3G2	5.35	15.49	41.93	2.3	34.37	–
Kh20N9G7T	12.5	29.69	12.35	–	13.63	23.52

ilar steels are formulated in the work [1]. According to them, in order to reduce the structural heterogeneity in the fusion zone with pearlitic steel, the welding wire should provide producing of weld metal with an austenitic structure, increased nickel content and minimum content of carbide-forming elements. It is recommended to determine the amount of nickel in welding wire depending on the maximum service temperature of welded joints. The recommended conformity of the composition of welding wire to the service temperature of welded joints of dissimilar steels [1] is as follows: for alloyed wire Kh20N9G7T the permissible service temperature is 350; for Kh25N25M3G2 — 450; for Kh25N40M6G2 — 550; for Kh25N60M10G2 — 650 °C. In this case the amount of carbide-forming elements is determined from the condition of providing a sufficient resistance of austenitic weld to formation of hot cracks. At the same time, the carbide-forming elements should have a relatively low activity with respect to carbon and their quantity should be minimal to reduce the diffusion of carbon and the formation of carbides in the fusion zone. As to activity, such elements are chromium, molybdenum, tungsten, the presence and quantity of which is determined by the content of nickel in the wire: the higher it is, the more these elements are in the composition of the wire.

The amount of chromium in the composition of high-nickel wires is limited to 25 %, and that of molybdenum — to 10 % (Table 1) due to their high tendency to σ-phase formation, embrittling the metal. The lower chromium content and the absence of molybdenum in the wire of type Kh20N9G7T are caused by the austenitic-ferritic structure of weld metal, which provides it with a sufficient technological strength.

During welding using high-nickel wires in the mixture of CO_2 with nitrogen the weld surface has a high roughness, in the depressions of which there is a larger amount of oxide crust. It practically does not break off and can be removed only applying abrasive disc. The weld surface, produced using the wire of type Kh20N9G7T, is smoother, and the oxide crust itself is separated from it in the process of cooling. At the same time, its thickness is in the range of 0.5–1.5 mm and has a shiny surface of fracture, characteristic for glass [11]. The chemical composition of oxide crust and its melting temperature depend on the composition of welding wire (Table 2, 3).

The analysis of state diagrams of binary systems formed by oxides, given in Table 2, shows that in the oxide crust of a high-nickel weld, the phases (FeMn)OCr_2O_3 and $FeCr_2O_4$MoO can form, which have a spinel lattice, isomorphic with the metal lattice [12].

The presence of titanium, increased content of silicon and also manganese in the wire of type Kh20N9G7T provides a more active interaction with oxygen than chromium and molybdenum. This reduces the amount of oxides of Cr_2O_3 and MoO_3, which, in its turn, reduces the temperature of melting (T_m) and glassing (T_{gl}) of the crust (Table 3) to a temperature which is lower than melting and solidification temperature (T_s) of weld metal. A good separation of oxide crust from the weld surface is explained by formation of a brittle glassy silicate phase in its composition [13, 14], which is cracked when the weld is cooled. The improvement of its separation is also facilitated by the presence of zirconium in the welding wire composition, which forms the zirconium oxides in the oxide crust, which have a higher coefficient of thermal expansion than the silicate phase, which contributes to its fracture when the weld is cooled [15].

A later solidification of oxide crust than that of the weld metal makes its surface smooth and the earlier solidification makes it rough. In the latter case, apparently, the capture of a solidified crust by liquid metal

Table 3. Temperature of aggregation state of weld metal and oxide film

Type of wire alloying	Weld metal		Oxide film	
	T_m, °C	T_s, °C	T_m, °C	T_{gl}, °C
Kh25N25M3G2	1470	1330	1811	1680
Kh20H9G7T	1460	1390	1300	960

is possible, which leads to deterioration of its separation.

The results of the analysis were checked by evaluation of separation of oxide crust from the surface of deposited metal produced by standard welding wires (GOST 2240–70), which were designed for welding of high-alloy steels.

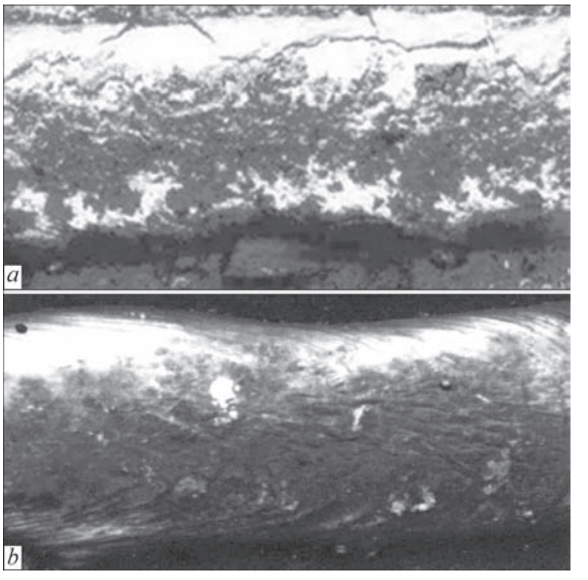
Evaluation of separability of oxide crust from weld surface

Sv-06Kh19N9T	Separated partially
Sv-08Kh20N9G7T	Complete self-separation
Sv-07Kh18N9TYu	Separated partially
Sv-05Kh20N9FBS	Separated partially
Sv-08Kh20N9S2BTYu	Separated completely
Sv-08Kh19N10G2B	Separated partially
Sv-07Kh25N13	Not separated
Sv-01Kh19N18G9AM4	Separated partially
Sv-10Kh16N25AM6	Not separated
Sv-01Kh23N28M3D3T	Not separated
Sv-08N60G8M7T	Separated partially
Sv-KhN75MBTYu	Separated partially

As is seen, only one welding wire Sv-08Kh20N9G7T has a chemical composition which provides a complete self-separation of the oxide crust during cooling (Figure, *a*). However, it should be noted that its separation can be deteriorated by reducing the amount of silicon, manganese and titanium in the composition of the wire within the limits of grade composition (Table 1). At the content of Si 0.62 %, Mn 5.8 %, Ti 0.7 % in wire composition the weld surface is completely covered with a black crust (Figure, *b*), which partially breaks off. A good separability of the oxide crust is observed in the presence of silicon and titanium in the wire Sv-08Kh20N9G7T, which is higher than 0.7 % and the ratio of its quantity to the amount of manganese is higher than 0.125. A significant deterioration in its separation, even when this ratio is satisfied, is observed with a decrease in the oxidizing capacity of shielding gas, for example, when using the mixture of argon with 0.5–4.0 % oxygen or with less than 40 % CO_2 as a shielding gas. The cause for this is a decrease in the composition of oxide crust of a brittle glassy phase and an increase in the oxides of the spinel-forming element — chromium, and also a decrease in its thickness to less than 0.5 mm. The role of the latter factor in this, obviously, is due to a decrease in the level of thermal stresses, which contribute to its cracking.

The separability of oxide crust is deteriorated also at the increase in nickel content in the wire composition, and also at the presence of aluminum, niobium, vanadium, which are the strong spinel-forming elements.

Thus, when selecting the chemical composition of austenitic high-nickel wires for mechanized welding of dissimilar steels in the mixture of shielding gas



Surface of beads, deposited in CO_2 using wire Sv-08Kh20N9G7T having a ratio Si/Mn: *a* — 0.142; *b* — 0.11

based on CO_2, the following factors should be taken into account:

● correspondence of nickel amount in the composition of welding wire to the service temperature of welded joint;

● in the welding wire a minimum amount of carbide-forming elements, such as manganese, chromium, molybdenum and other should be present, sufficient to provide a high resistance of weld metal to hot cracks formation;

● to improve the separation of the oxide crust from the weld surface, the following elements of chemical composition of the wire should be in an increased amount: silicon, titanium, zirconium, manganese, etc., which form the brittle phases of glassy morphology in the composition of the oxide crust, as well as have a higher activity of interaction with oxygen than chromium, molybdenum and other elements, which are spinel-forming.

Conclusions

1. The application of mechanized arc welding of dissimilar steels in shielding gas based on CO_2 is limited in connection with formation of a refractory oxide crust on the surface of deposited high-nickel metal and appearance of defects in the multilayer weld such as lacks of fusion and slagging.

2. The composition of welding wire for mechanized arc welding of dissimilar steels in shielding gas based on CO_2 should have, except of a high content of nickel and the minimum amount of carbide-forming elements, such as chromium, molybdenum, tungsten, etc., an increased content of such elements as silicon, titanium, manganese, etc., forming a phase of glass-

like morphology in the composition of oxide crust and lowering the temperature of its solidification.

3. The quality of multilayer weld of welded joints of dissimilar steels during mechanized welding in shielding gas based on CO_2 is provided by applying the electrode welding wire of grade Sv-08Kh20N9G7T, in the composition of which a quantity of silicon and titanium is higher than 0.7 %, and the ratio Si/Mn is higher than 0.125.

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