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Dependence of Manganese Content in the Weld Metal on the Velocity of Active Shielding Gas Flow

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Abstract. The paper reports findings of the study on influence of changing active shielding gas flows on consumable electrode welding and manganese content in the weld metal. A procedure to predict manganese content in the weld metal according to the velocity of a shielding gas flow, manganese content in electrode wire and base metal is proposed. A regression dependence of manganese content in the weld metal on the velocity of active shielding gas flow from the nozzle is determined.

Introduction

Gas-shielded arc welding follows the principle of pushing air aside from the weld zone by a shielding gas flow. To date, a number of gas-shielded welding techniques are available and used in manufacture [1]. Noble (argon, helium), active (nitrogen and CO_2) gases and their mixtures are applied as shielding gases. Properties of shielding gases are crucial for technological characteristics of arc and weld forms.

Jet shielding is the most wide-spread procedure of local protection in welding. Crystallization velocity of the weld metal depends on shieling gas consumption and a gap from the nozzle exit to the surface of material to be welded. When jet gas-shielded welding it is the fusion zone, which is protected. In local jet shielding the flow of gas is laminar but it turns into a turbulent one (with heavy whirls) as the velocity of shielding gas flow increases critically and a laminar flow fails. Here, up to 50% air is admixed into a shielding gas jet at a distance of several millimeters (6-10mm) [1].

The authors [2-8] studied the effect of changing shielding gas flows on consumable electrode welding and emphasized the improvement of weld zone protection, weld shaping, and welding stability owing to increased gas flow velocity.

In works [5, 9] it is described how the velocity of shielding gas supply influences transfer of electrode metal drops, and its value, furthering separation of a drop, is determined (it depends on dimensions of a drop and electrode metal). The researchers [3, 10] point at the improvement of welding stability, shaping and density of a weld when supplying of shielding gases (Ar, He) is alternated in consumable electrode welding.

In comparison with conventional shielding, two-jet gas shielding [11] provides a reliable protection of a weld pool, improves stability and frequency of drop transfer from the electrode into a weld pool, furthers refinement of weld metal structure and smooth transition from the weld metal to the base one, enhances mechanical characteristics of weld joints, and decreases chemical inhomogeneity of the weld metal due to a positive gas-dynamical effect on processes in the weld zone and better remixing of fused metal in the weld pool.

Methodology

As the velocity of active shielding gas flow from the nozzle increases, dynamic impact on a drop of electrode metal goes up in two-jet gas shielding, transfer of drops from the electrode into the weld pool gets stable and more frequent, and metallurgical processes on the surface of a drop become more intense. When welding constructional steels it is required to use a welding wire with manganese content exceeding that in the base metal. The reason is that manganese evaporates and gets oxidized intensively in welding [1, 12]. Therefore, welding wire Sv-08G2S (Tabl. 1) with a diameter of 1.2 mm is applied widely in Russian industry.

Table 1

Chemical composition of welding wire Sv-08G2S (GOST 2246-70)

Mass share of elements, %						
C	Mn	Si	S	P	Cr	Ni
0.05-0.11	1.8-2.1	0.7-0.95	≤ 0.025	≤ 0.03	≤ 0.2	≤ 0.25

In previous experiments [2, 11-13] it is revealed that in two-jet gas-shielded welding with a consumable electrode in CO_2 and its mixtures the process stabilizes, and Mn and Si content decreases slightly in the weld metal as compared with samples made with one-jet shielding. This difference in Mn and Si content when welding in similar conditions can be accounted only for different metallurgical processes taking place in a drop of fused electrode metal and on its surface. A lot of scientists emphasized in their works [1, 3, 9, 14 etc.] more favorable conditions for reaction of fused metal with gases and slags in the phase of a drop rather than in the weld pool. As stated in paper [1], a specific surface of fused electrode metal drops is 5-22 times bigger (depending on dimensions of drops) than a specific surface of a weld pool, and a specific velocity of their oxidation is approximately 39 times faster. Hence, it can be concluded that, basically, chemical composition of the weld metal influences composition of electrode metal drops.

Fused (liquid) metal in a drop moves constantly at a high speed. Manganese has the lowest boiling temperature and evaporation heat of all alloying elements in chemical composition of welding wire Sv-08G2S (Table 2). It is the reason for its intense evaporation and oxidation on the surface of a drop when welding, the temperature of which approximates to 3300 K [1, 14].

Table 2

Thermo-dynamical characteristics of elementary substances (in normal conditions) in chemical composition of the welding wire [15]

Characteristic	Substance							
	Mn	Si	Cr	Ni	Fe	Ti	Mo	C graphite
Boiling temperature, K	2235	2623	2945	3005	3134	3560	4885	5100
Evaporation heat, kJ/mole	221	383	342	378.6	340	422.6	590	-
Fusion temperature, K	1517	1688	2130	1726	1812	1933	2890	3820
Density, g/cm^3	7.21	2.33	7.19	8.9	7.87	4.54	10.22	2.25

Increasing consumption of CO_2 in welding, i.e. velocity of flow and number of particles reacting with the surface results in the heightened burn out of silicon and manganese [1, 12, 14].

In two-jet gas shielding the velocity of gas flow is 3.5 times higher than in one-jet shielding, causing, this way, augmentative frequency of drop transfer, drop diminishment and growth of the total active surface of drops carried from the electrode into a weld pool per unit of time. It results in removal of a lot of manganese from the surface of a drop. Therefore, electrode metal with less content of manganese is transferred into the weld pool. Manganese content in a drop decreases with rising CO_2

consumption in welding with any jet shielding. The amount of manganese transferred from the electrode into the weld might make it possible to predict chemical composition and characteristics of the weld metal.

Studying findings of research [1, 11-14], it was revealed that chemical composition of the weld metal, manganese and silicon content in particular, depends on several factors, e.g. temperature of a drop (welding current strength, voltage, technique of gas shielding), time of reaction between a drop and a shielding gas (welding current strength, consumption and gas velocity – the time reduces with their increase), drop dimensions (welding current strength, gas consumption and velocity – a drop gets smaller with their increase), welding wire and base metal composition.

Manganese and silicon content increases in the weld metal [1, 11-14] due to intensifying welding current, whereas it drops with augmentation of voltage. Decreasing manganese and silicon content in the weld metal is registered with rising velocity of shielding gas (CO_2) in open arc welding [1, 12, 14]. Manganese is one of basic elements, since it has a low deoxidizing power and can intensify influence of other elements, resulting, therefore, in change of weld metal properties.

In arc welding with consumable electrode in CO_2 thermal dissociation of carbon dioxide takes place at high temperatures according to an equation:

$$CO2 = CO + O \quad (1)$$

CO_2 dissociates in a high-temperature area of the weld zone [14], approximately 50% gas dissociates when reacting with the surface of a fused metal drop surface (above 3000 °C). Oxygen, which is a product of reaction, can oxidize components of the welding wire:

$$Si + 2O = SiO2\ , \quad (2)$$

$$Mn + O = MnO \quad (3)$$

$$C + O = CO \quad (4)$$

$$Fe + O = FeO \quad (5)$$

Results and Discussion

Experimental studies were conducted to determine an empirical dependence of manganese content in the weld metal on the velocity of shielding gas (CO_2) flow. Mechanized single-pass beading with welding wire Sv-08G2S of a diameter 1.2 mm was carried out in CO_2 with a stationary arc on a plate of steel 45 with two-jet gas shielding. Welding conditions: welding current I = 195...200 A, electrode wire extension L = 12 mm, arc voltage U = 26…27 V, velocity of welding V = 20 cm/min. shielding gas consumption Q = 10, 20, 30 l/min (Table 3). Equipment used: automatic welding unit MECOME WP1500 power source VS–300B and a supplying mechanism PDGO-528M. Outcomes of research are given in Table 3.

Table 3

Experimental results

Consumption, l/min	Gas flow velocity, m/s	Chemical composition of the weld metal, %		
		Fe	Si	Mn
10	1.96	97.55	0.28	1.04
20	3.95	97.73	0.27	0.97
30	5.82	97.91	0.21	0.85

Manganese content, % vs. its initial state in the wire is calculated according to a formula:

$$\Delta C_{(\%)} = \frac{m_{Mn}^{k}}{m_{Mn}} 100\% \quad (6)$$

where m_{Mn}^{k} – mass share of manganese in a drop after passing of a gas jet (Table 3, Mn), %,

m_{Mn} – initial mass share of manganese in a welding wire (Sv-08G2S – 1.8%), %.

Experimental values of manganese content, % in a drop vs. its initial state in the wire (Table 3) were approximated:

$\Delta C_{Mn} = 62.3 - K*Vg$ (7)

where K = 1.97 – coefficient, %*s/m; Vg – velocity of a shielding gas flow, m/s.

Taking into account theoretical and experimental studies on consumable electrode narrow-gap welding of constructional steels in CO_2, a procedure was developed to predict manganese content in the weld metal depending on the velocity of a shielding gas flow, and manganese content in the electrode wire and base metal.

Predicted manganese content Mn in the weld metal (mass share, %):

$$m_{Mn\_w} = \frac{m_{Mn} \cdot \Delta C_{Mn_w}}{100\%} \quad (8)$$

Manganese content in the weld metal (%) vs. its initial state in the wire and according to the velocity of a shielding gas flow from the nozzle and manganese content in the base metal:

$\Delta C_{Mn\,w} = 62.3 + Mn_{bm}*10 - K2*Vg$ (9)

where K2 = 1.55 – coefficient, %*s/m; Mn_{bm} – Mn content in the base metal (mass share, %), Vg – shielding gas flow velocity, m/s.

To compare predicted values obtained using this procedure with experimental data, results of experiments conducted before on steels 45, 30HGSA and GL-E36 [11, 12] were used.

Plates of the base metal were joined by mechanized multi-pass keyhole welding with Mn containing welding wire of a diameter 1.2mm in CO_2 with a stationary arc in one-jet and two-jet gas shielding. Welding conditions: welding current I = 195...200 A, electrode wire extension L = 12 mm, arc voltage U = 26…27 V, velocity of welding V = 19...21 cm/min. Shielding gas consumption Q = 10...30 l/min (Table 4).

Table 4

Predicted and experimental values of Mn content in the weld metal

Base material + welding wire	Gas flow velocity, m/s	Prediction Mn, %	Experiment Mn, %	Percentage error, %
30HGSA (Mn=0.96%) + Sv-08G2S (Mn=1.8%). One-jet	0.58	1.27	1.29	1.6
30HGSA (Mn=0.96%) + Sv-08G2S (Mn=1.8%). Two-jet	2.0	1.23	1.26	2.3
30HGSA (Mn=0.96%) + Sv-08G2S (Mn=1.8%). Two-jet	4.95	1.14	1.2	5.0
GL-E36 (Mn=1.25%) + Union K 52 (Mn=1.5%). One-jet	0.5	1.11	1.2	7.5
GL-E36 (Mn=1.25%) + Union K 52 (Mn=1.5%). Two-jet	2.1	1.07	1.05	1.9
Steel 45 (Mn=0.67%) + Sv-08G2S (Mn=1.8%). One-jet	1.45	1.2	1.21	0.8
Steel 45 (Mn=0.67%) + Sv-08G2S (Mn=1.8%). Two-jet	5.06	1.1	1.11	0.9

The results of the research show that the developed method for predicting the manganese content in the weld metal (keyhole welding), based on the escape velocity of the shielding gas and the manganese content in the electrode wire and the base metal, allows calculating the manganese content mainly with an error of no more than 10%.

Conclusion

Two-jet gas shielding intensifies the effect of an active shielding gas jet on the electrode metal drop and surface of the weld pool and facilitates stability of drop transfer. Changing gas-dynamic influence (gas consumption, gas flow velocity), transfer of electrode metal drops, chemical composition of the weld metal, thermal and other processes of consumable electrode welding can be controlled, and required characteristics of the weld metal can be formed.

The developed procedure for prediction of manganese content in the weld metal depending on the velocity of shielding gas flow, manganese content in the electrode wire and base metal allows calculation of manganese content in the weld metal with maximal error 10%.

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