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Dependence of Silicon and Manganese Content in the Weld Metal on the Welding Current and Method of Gas Shielding

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Abstract: The influence of the welding current and method of gas shielding in MAG welding on the content of silicon and manganese is considered. Results of study of the welded specimens of steels 45 and 30HGSA when applying welding wire of different formulas and different types of gas shielding (traditional shielding and two-jet shielding) are given. It is established that in MAG welding the value of the welding current and the speed of the gas flow from the welding nozzle have a considerable impact on the chemical composition of the weld metal. The consumable electrode welding under double-jet gas shielding provides the directed gas-dynamics in the welding area and enables controlling the electrode metal transfer and the chemical composition of a weld.

Introduction

At present welding is widely applied to obtain permanent connections from a wide range of metallic and non-metallic materials and structural composites in the Earth's atmosphere, in the World Ocean and in the Space. In spite of constantly increasing application of light alloys, polymer materials and composites in constructions and articles, steel is still used as the main engineering material. The global market of welding equipment and services is expanding proportionally to the growth of world steel consumption.

Welding processes develop according to complex physical and chemical laws under high temperature. The complex of various factors and phenomena influences on the quality of joint welds. This influence is particularly significant when hardenable items welding. New welding technologies are developed and the early ones are improved constantly as well as welding techniques, methods, weld properties and configuration control [1–7].

Methodology

This work is aimed at the study of the influence of active shielding gas (CO_2) and welding current consumption on Mn and Si level in weld metal in consumable electrode welding.

In consumable electrode gas shielded welding of steels the chemical composition of weld metal depends on molten electrode and base metal shares, reaction intensity in a drop and the weld pool, the loss of elements from molten electrode and base metals [1, 2, 7] as well as on shielding gas consumption and its chemical composition [1, 2, 6, 7].

Results and Discussion

Mn and Si level in weld metal decreases as shielding gas CO_2 outflow rate rises in open-arc welding the diameter of wire is 1.2 mm [6, 7]. The experiments carried out on multi-layer 45 steel welded samples with welding wires of various composition (Sv-08G2S, Sv-08GSMT) and various methods of gas shielding (the traditional one and double-jet shielding) demonstrated the dependence of Mn and Si level in weld metal on welding current (Tables 1–3). The obtained results demonstrate the influence of welding current and gas outflow rate on the chemical composition of weld metals and, consequently, their performance characteristics.

From 250A (U = 27V, l = 12 mm), when the arc becomes submerged, Mn in weld metal is getting practically stabilized, moreover, its level is much higher than that in weld metal when in open-arc welding (140–220 A).

Table 1
Chemical composition of the base and materials

Material	Weight fraction of elements, [%]						
	C	Mn	Si	Cr	Ni	Mo	Ti
According to the steel grade guide [9]							
Steel 45	0.42–0.5	0.5–0.8	0.17–0.37	≤ 0.25	≤ 0.3	–	–
Sv-08G2S	0.05–0.11	1.8–2.1	0.7–0.95	≤ 0.2	≤ 0.25	–	–
Sv-08GSMT	0.08–0.12	1.0–1.3	0.4–0.7	≤ 0.3	≤ 0.3	0.2–0.4	0.05–0.12
Averaged results of experiments							
Steel 45	0.44	0.67	0.31	0.19	0.11	–	–
Sv-08G2S	0.07	1.80	0.78	0.06	0.07	–	–
Sv-08GSMT	0.12	1.12	0.54	0.15	0.14	0.21	0.054

Table 2
Averaged research results of chemical composition of weld metal in 45 steel samples, welded with Sv-08G2S wire in CO_2 (U = 27V, l = 12 mm, Q = 25 l/min, V_w = 20 cm/min)

Welding current, [A]	Weight fraction of elements, [%]				
	C	Mn	Si	Cr	Ni
	Traditional single-jet gas shielding				
140	0.120	1.205	0.430	0.080	0.100
190	0.140	1.214	0.450	0.090	0.100
230	0.152	1.264	0.461	0.089	0.098
280	0.150	1.461	0.556	0.096	0.104
	Double-jet gas shielding				
140	0.145	1.066	0.342	0.082	0.092
190	0.133	1.104	0.379	0.098	0.103
230	0.135	1.243	0.444	0.080	0.097
280	0.165	1.363	0.534	0.108	0.092

In traditional open-arc gas shielded welding with Sv–08G2S wire in the current range 140–190 A 30–35 % manganese is burnt out (0.58–0.6 % the weight fraction), and in welding at 280 A about 20% manganese (0.32–0.35 % the weight fraction) is burnt out when consumption of the shielding gas (Tabl. 2, fig. 1, a) held equal. The less manganese burnout is possible as welding wire feed rate is increased, transfer of a drop into the weld pool is getting faster, and the time of drop overheated condition is reduced. In the same conditions in double-jet gas shielding welding the burnout of manganese increases and amounts to about 36–41 % (0.7–0.74 % the weight fraction) and 24 % manganese (0.4–0.44 % the weight fraction), consequently. This fact demonstrates the growing gas-dynamic impact on drop of molten metal and more intensive metallurgical processes.

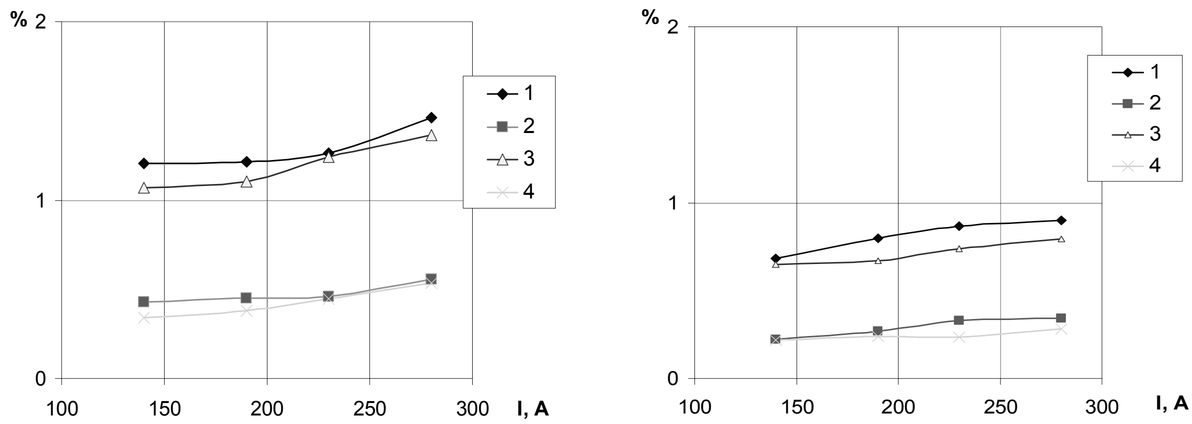
The situation is similar in welding with Sv–08GSMT wire (Tabl. 3, Fig. 1, b). In traditional open-arc gas shielded welding in the current range 140–190 A 30–40 % manganese is burnt out (0.33–0.44 % the weight fraction), and in welding at 280 A about 20% manganese (0.21–0.23 % the weight fraction) is burnt out when the consumption of the shielding gas held equal. In double-jet gas shielding welding the burnout of manganese is 39–42 % (0.45–0.47 % the weight fraction) and 29 % (0.32–0.34 % the weight fraction), respectively.

It's determined that the percentage of manganese burnout while transfer from a wire into a weld stays nearly similar and amounts to 35% at the current up to 200 A, and about 20% at the current up to 280 A, but the weight fraction of the burnt out manganese changes depending on the initial level in a welding wire. The manganese level in weld metal differs from that of the initial level in a welding wire and amounts to about 5% in the traditional single-jet and double-jet gas shielding.

Table 3
Averaged research results of the chemical composition of weld metal of 45 steel samples, welded with Sv-08GSMT wire in CO_2 (U = 27V, l = 12 mm, Q = 25 l/min, V = 20 cm/min)

Welding current, [A]	Weight fraction of the elements, [%]						
	C	Mn	Si	Cr	Ni	Mo	Ti
	Traditional single-jet gas shielding						
140	0.184	0.682	0.221	0.120	0.122	0.16	0.012
190	0.124	0.796	0.268	0.130	0.143	0.17	0.017
230	0.136	0.864	0.328	0.125	0.126	0.17	0.019
280	0.144	0.901	0.341	0.167	0.150	0.17	0.019
	Double-jet gas shielding						
140	0.206	0.652	0.212	0.135	0.131	0.16	0.015
190	0.161	0.669	0.229	0.126	0.127	0.15	0.01
230	0.151	0.739	0.235	0.148	0.137	0.15	0.012
280	0.169	0.792	0.280	0.147	0.134	0.15	0.018

In open-arc welding the magnitude of the welding current and active gas outflow rate from the welding nozzle have a considerably influence on the chemical composition of weld metal. In double-jet gas shielding with increase in the impact of active shielding gas jet on a drop of electrode molten metal the intensity of metallurgical processes on the drop surface rises [10].



a) b)

Fig. 1. The dependence of Mn and Si level in weld metal of 45 steel joint welds:
a) welding with Sv–08G2S wire; b) welding with Sv–08GSMT wire.
Traditional single-jet gas shielding: line 1 – Mn, line 2 – Si;
Double-jet gas shielding: line 3 – Mn, line 4 – Si

Many scientists in their works [1–7, 11] note the more advantageous conditions of interaction between metal and gas and slays at the stage of a drop as against the weld pool. In his work Novozhilov M.N. states [2] that the specific surface area of molten metal drops is 5–22 times (in accordance to the drop size) bigger than the specific surface of a weld pool and their specific oxidation speed is about 39 times higher. A conclusion can be made, that the chemical composition of weld metal determines basically the chemical composition of electrode molten metal drops.

The analysis of the results of research [1, 2, 6–8, 10] demonstrated, that the chemical composition of weld metal, especially Mn and Si levels depends on a lot of factors: the temperature of a drop (welding current strength, voltage, gas shielding method), the time of interaction between a drop and shielding medium (welding current strength, consumption and gas outflow rate – they increase and the time reduces), the drop size, welding wire chemical composition, base metal chemical composition. With increase in the welding current Mn level grows in weld metal, and with increase in the voltage its level falls. The decrease in Mn and Si level in weld metal occurs as the consumption of the shielding gas (CO_2) increases in open-arc welding.

Among all alloying elements that are parts of welding wires manganese has the lowest boiling temperature and the heat of vaporization (Tabl. 4). This fact causes its intense vaporization and oxidation on the surface of molten metal drop, which temperature is about 3000 K [2].

Table 4
Thermal-dynamical properties of elementary substances which are parts of the chemical composition of a welding wire (in initial conditions) [12]

Item	Substance							
	Mn	Si	Cr	Ni	Fe	Ti	Mo	C Graphite
Boiling temperature, [K]	2235	2623	2945	3005	3134	3560	4885	5100
Melting temperature, [K]	1517	1688	2130	1726	1812	1933	2890	3820
Vaporization temperature, [kJ/mole]	221	383	342	378,6	340	422,6	590	–
Density, [g/cm^3]	7.21	2.33	7.19	8.9	7.87	4.54	10.22	2.25

The gas-dynamic impact of the active shielding gas in double-jet gas shielded welding on the chemical composition of weld metal in single-pass joint welds of 30HGSA steel [13, 14] confirms the carried out research on complete factorial experiment method.

The mechanized single-pass welding of 30HGSA steel plates 150x300 mm in size and 8 mm thick was completed with Sv–08G2S welding wire 1.2mm in diameter in CO_2 and the stationary arc under double-jet gas shielding without preheating and following-up heat treatmentThe directed parameters were varied on two levels: welding current I_1 = 170A and I_2 = 200 A, extension of the electrode wire L_1 = 8 mm and L_2 = 14 mm, shielding gas consumption Q_1 = 15 l/min and Q_2 = 20 l/min. Arc voltage U = 26…27 V, welding rate V = 25…26 cm/min.

On the basis of the experiments the dependences of chemical elements levels (Si, Mn) in weld metal of single-pass 30HGSA steel joint welds on directed parameters (Q, L, I) are developed. The latter are non-dimensional values (x_1 – Q, x_2 – L, x_3 – I), changing in the range from –1 to +1. The ratio error of calculations doesn't exceed 10 %:

1. The dependence of Si level upon the directed parameters.

$$Si = 0.728 + 0.02 \cdot x_2 + 0.03 \cdot x_1 \cdot x_2 \cdot x_3 \quad (1)$$

3. The dependence of Mn level upon the directed parameters.

$$Mn = 1.158 - 0.02 \cdot x_1 + 0.022 \cdot x_3 - 0.015 \cdot x_1 \cdot x_3 + 0.018 \cdot x_2 \cdot x_3 + 0.055 \cdot x_1 \cdot x_2 \cdot x_3 \quad (2)$$

It's determined that the carbon level in weld metal of single-pass 30HGSA steel joint welds (in conditions of the experiment) doesn't depend on the directed parameters (Q, L, I). The shielding gas consumption Q influences on Mn levels in weld metal, its increase causes the fall of Mn level. The increase in shielding gas consumption raises its outflow rate from the welding nozzle (inner jet), the jet of the shielding gas takes more vaporizing manganese. The increase in the extension of the electrode wire L causes the increase in Si level in weld metal. It's possible as the arc voltage falls and influences the Si burn-out under welding [1, 7, 8]. The increase in the welding current I increases Mn level. The stable welding under the increase in the current is provided with the growth of in the welding wire feed rate, namely, accelerates the drop transfer into the weld pool and the time when the drop overheated is shortened.

Conclusion

It's determined that in consumable electrode welding in CO_2 and its mixtures the welding current magnitude and the gas outflow rate from the welding nozzle (gas consumption, method of gas shielding, electrode extension) are of significant importance for the chemical composition of weld metal. The consumable electrode welding under double-jet gas shielding provides the directed gas-dynamics in the welding area and enables controlling the electrode metal transfer and the chemical composition of a weld, stabilizing the welding process.

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