Manganese Content Control in Weld Metal During MAG Welding

D A Chinakhov[1], E D Chinakhova[2], A S Sapozhkov [1]

[1]Yurga Institute of Technology of National Research Tomsk Polytechnic University, 652055, Leningradskaya st., 26, Yurga, Kemerovskaya region, Russia
[2]Siberian State Medical University, 634055, Moskovsky trakt 2, Tomsk, Russia

e-mail: chinakhov@tpu.ru

Abstract. The influence of the welding current and method of gas shielding in MAG welding on the content of manganese is considered in the paper. Results of study of the welded specimens of steels 45 when applying welding wire of different formulas and different types of gas shielding (traditional shielding and double-jet shielding) are given. It is found 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 joints 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 the quality of joint welds. This influence is particularly significant in welding hardenable items. New welding technologies are developed and the early ones are steadily improved. Welding techniques, methods, weld properties and configuration control are also being improved [1–7].

The main role in the formation of welded joints belongs to the processes occurring in a drop of molten metal and the electrode metal in the weld pool [1, 2, 3, 13]. The speed and completeness of the physical and chemical processes in the electrode metal droplet formation determine the quality of the weld and its chemical composition [12, 13]. Welding current, arc voltage, chemical composition of the electrode wire, size and droplet growth time, the frequency of droplet transfer from the electrode to the weld pool, the composition of the shielding gas and its rate of flow from the torch [12, 13,] influence the processes taking place in a drop of molten electrode metal significantly.

Methodology

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

When welding steels with consumable electrode in shielding gas, the composition of the weld metal depends on the share of the electrode and the base metal, the intensity of the reactions in the droplet and the weld pool, the loss of elements of the electrode and the base metal [1, 2, 7], as well as the flow rate and the composition of the shielding gas [1, 2, 6, 7].

We conducted a comparative calculation of the speed of the shielding gas flow from the nozzle of the traditional single-jet nozzle (cone type) and from the designed double-jet shielding nozzle (Table 1). The shielding gas is CO_2, gas density b is 1.97 kg/m^3, gas flow rate Q is 20 l/min.

The results of the calculations show that in double-jet shielding the speed of the gas flow from the nozzle is 2.1 times higher than in one-jet shielding, the gas flow rate being the same [16, 17]. To check the adequacy of the calculated data we conducted an experiment. Under laboratory conditions, using a hot-wire anemometer Dwyer Series 471, we measured the speed of shielding gas flow at the nozzle exit at different flow rates (Table. 1).

Table 1.

The speed of flow of gas through a nozzle and the power of the shielding gas jet

Method	Sectional area S, mm^2	Gas rated speed, м/с	Experimentally measured speed of gas flow, м/с
Single jet	173	1.93	1.83
Double jet	82	4.05	3.95

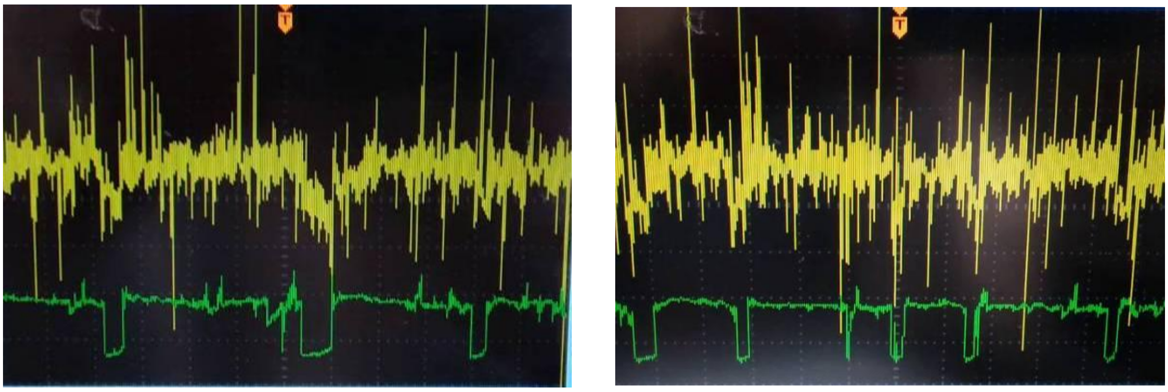
Comparing the calculated and experimental data showed that the relative error does not exceed 10%, and developed a model for calculating the shielding gas flow through nozzle provides a satisfactory accuracy [16, 17].

Results and Discussion

To assess the impact of the shielding gas flow through nozzle speed on the transfer of electrode metal droplets to the weld pool we made a high speed recording of waveforms of current and voltage (Fig. 1) with a digital oscilloscope Agilent Technologies DSO1012A.

We made a weld bed with welding wire Sv-08G2S diameter of 1.2 mm in CO_2 shielding gas The weld bed was made using a single-jet (cone type nozzle) and a double-jet gas shieldong. Welding conditions: I = 200 A, arc voltage U = 26 V, welding wire extension L = 12 mm, the shield gas flow Q = 20 liters/min. The experiments were performed under the same conditions and the same modes. The power supply sources were VS-300B, welding machine was VD - 1500.

Analysis of the waveforms has shown, that with increasing the speed of the shielding gas though nozzle (double-jet), gas-dynamic effect on the droplet of the electrode metal is also increased, the frequency of droplet transfer from the electrode to the weld pool (an average of 1.6 times as compared with the single jet gas shield), and the intensity of the metallurgical processes on the surface of the drop increases too, the droplet size decreases as the droplet transfers to the weld pool (Fig. 1).



a) b)

Fig. 1. Waveforms of current and voltage: a) Traditional Single-jet gas shielding; b) double-jet gas shielding

Mn content in weld metal decreases as shielding gas CO_2 flow 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 level in weld metal on welding current (Tables 2–4). 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 2

Chemical composition of the base and materials

Material	Weight fraction of elements, [%]				
	C	Mn	Si	Cr	Ni
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
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

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. 3, 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.

Table 3

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

The situation is similar in welding with Sv–08GSMT wire (Tabl. 4, 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.

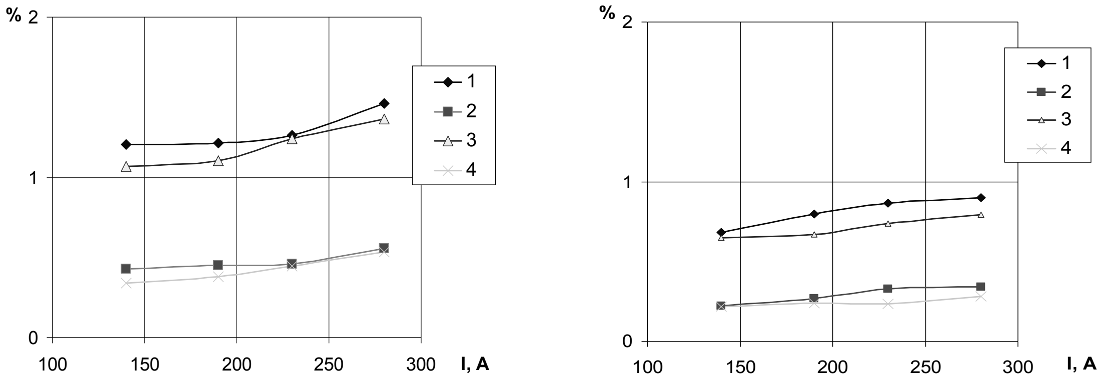
It's determined that the percentage of manganese burnout while transfer from a wire into a weld stays nearly similar and amounts to 35% at the current up to 200 A, and about 20% at the current up to 280 A, but the weight fraction of the burnt out manganese changes depending on the initial level in a 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 4

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. 2. 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. Work [2] states 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. 5). This fact causes its intense vaporization and oxidation on the surface of molten metal drop, which temperature is about 3000 K [2]. Increasing electrode metal droplets heating temperature rises manganese evaporation from its surface and the manganese content the in the weld metal reduces.

Table 5

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
Vaporization temperature, [kJ/mole]	221	383	342	378.6	340	422.6	590	–
Boiling temperature, [K]	2235	2623	2945	3005	3134	3560	4885	5100
Melting 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

On the other hand, when the current increases in mechanized welding with consumable electrode, the manganese content in the weld metal is increased. Stable welding process with increasing welding current provides for increased wire feed rate, i.e. it speeds up the transfer of droplets into the weld pool and reduces the time of its stay in the superheated state.

Double-jet shielding causes the increase in the force of active shielding gas impact on the filler metal drop and surface of the weld pool. When varying the gas-dynamic impact (consumption and rate of gas flow), transfer of filler metal drops, stability of the welding process, as well as chemical composition of weld metal, thermal and other processes in consumable electrode welding can be controlled, and required properties of joint weld can be formed [13-15].

Conclusion

It was found that in MAG welding in CO_2 the welding current magnitude and the gas flow rate though 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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