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The Influence of Shielding Gas Flow Rate on the Transfer Frequency of Electrode Metals Drops

D A Chinakhov, E G Grigorieva, E I Mayorova, D S Kartsev

Yurga Institute of Technology, National Research Tomsk Polytechnic University, 652055, Leningradskaya st., 26, Yurga, Kemerovo region, Russia

e-mail: chinakhov@tpu.ru

Abstract. Chemical composition of weld metal and properties of a joint weld are dominated by the processes occurring in the drop of molten electrode metal and in metal of the weld pool. Under certain conditions in consumable electrode welding with jet gas shielding the drop of electrode metal is influenced significantly both by main forces and the force of gas-dynamic impact of the shielding gas jet. The results of research have revealed that changing rate of shielding gas flow on the nozzle section influences the processes taking place in the welding area. There are changes in the transfer frequency of electrode metal drops and chemical composition of weld metal.

Introduction

Welding processes progress fast according to complex physical and chemical laws at high temperature. Diverse factors and phenomena dominate properties of joint welds. Formation of the structure and phase state of metal to be jointed depend on its chemical composition and conditions of thermal impact (mode and conditions of welding) [1-12]. Processes taking place in the drop of electrode metal and in metal of the weld pool are very important for properties of joint welds [1, 2, 3, 13]. The rate and character of physical and chemical processes in the drop of electrode metal influence properties of a weld and its chemical composition [12, 13].

The electrode metal transfer depends on various factors in the welding area. It is well-known [1, 3, 11] main forces like pressure force of arc plasma flows, surface tension force, reactive force of evaporating metal and emitting gas, gravitation force and electro-dynamic force effect on the drop of molten electrode metal when consumable electrode welding with traditional one-jet gas shielding. Components of these forces are dominated by the conditions of arc burning, electrode materials, welding current strength, arc voltage, traverse speed of filler wire and drop. The most forces depend on the size of electrode metal drop and its location relative to the weld pool. These forces, depending on their direction, can either block or further the transfer of electrode metal.

When consumable electrode welding with jet gas shielding in certain conditions the drop of electrode metal is influenced significantly both by main forces and the force of gas-dynamic impact of the shielding gas jet [2, 12], which depends on the mode and composition of gas shielding in the welding area, and the rate of shielding gas flow from the nozzle. Considerable influence of this force and the rate of gas flow have been revealed in conditions of two-jet gas shielding in CO_2 [12, 14].

Methodology

The force of shielding gas impact F_G depends on the rate of shielding gas flow from the nozzle; it is directed along the electrode towards the workpiece to be welded, and supports positioning of the drop along the electrode axis (Fig. 1).

The pressure on a drop is assumed to be equal to the pressure on the nozzle section in order to describe how the shielding gas jet influences the drop of electrode metal.

The gas pressure on the nozzle section was calculated by formula [15]:

$$P = \frac{bV^2}{2}, \tag{1}$$

where b – density of gas, kg/m^3, V – flow rate, m/s.

The flow rate was determined by formula:

$$V=G/S, \tag{2}$$

where G – consumption of shielding gas, m^3/s; S –area of nozzle section, m^2.

The force of shielding gas impact on the drop of electrode metal was measured by formula [12]:

$$F_{\mathrm{G}} = Pc_x 2\pi r_k \sqrt{r_k^2 - r_{\mathrm{w}}^2} \tag{3}$$

where P – pressure of shielding gas on a drop surface, Pa; r_k – a drop radius, m; r_w – a filler wire radius, m; c_x – aerodynamic drag coefficient of a sphere, c_x = 0.48.

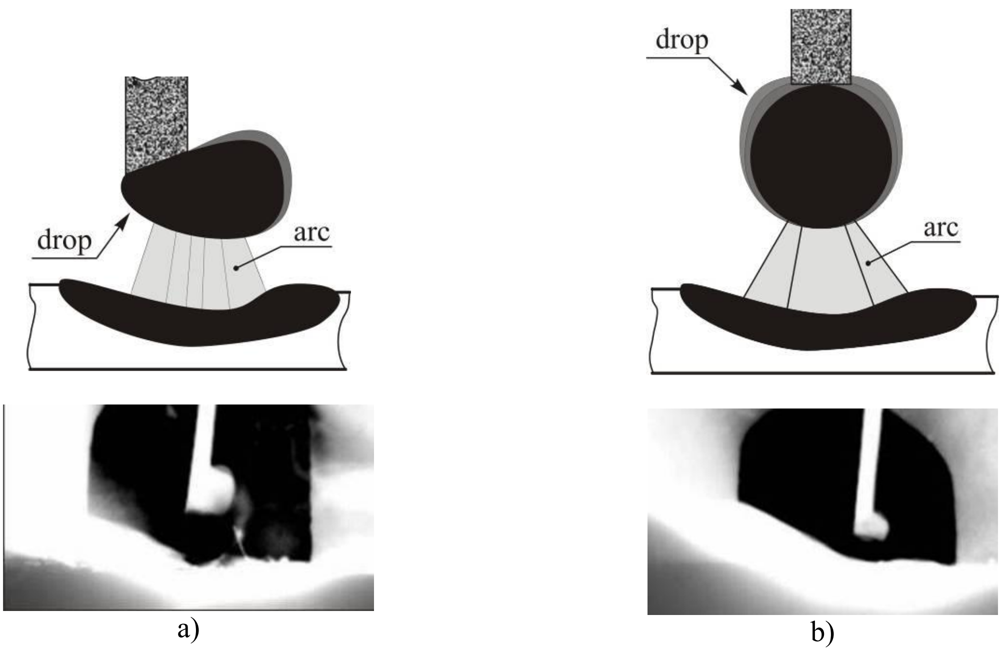


Figure. 1. The impact force of shielding gas jet on the drop: a) traditional one-jet gas shielding; b) two-jet gas shielding

The flow rate of shielding gas from the nozzle was determined, as well as the force of shielding gas impact on the drop of electrode metal was calculated. Comparative calculation was carried out for traditional one-jet (conic nozzle) and the proposed two-jet gas shielding (Tabl. 1). Shielding gas - CO_2, density of gas b =1.97 kg/m^3, consumption of gas Q = 20 l/min.

Results and Discussion

The results of calculation have stated that the rate of gas flow increases by 2.1 times when leaving the nozzle and the force of shielding gas impact augments by 4.39 times (similar consumption of gas) in conditions of double-jet shielding as against one-jet shielding (conic nozzle) [16, 17].

Table 1

The rate of gas flow on the nozzle section and the force of shielding gas jet impact

Method	Section area S, mm^2	Rate of flow V, m/s	Force of shielding gas jet F_G, $H*10^{-4}$
One-jet	173	1.93	5.02
Double -jet	82	4.05	22.04

An experiment was carried out to verify data obtained in calculations. In laboratory conditions rates of shielding gas flows were measured on the nozzle section by thermal mass flow meter Dwyer Series 471 provided that consumption of gas is different (Tabl. 2).

Table 2

Calculated and experimental rates of shielding gas

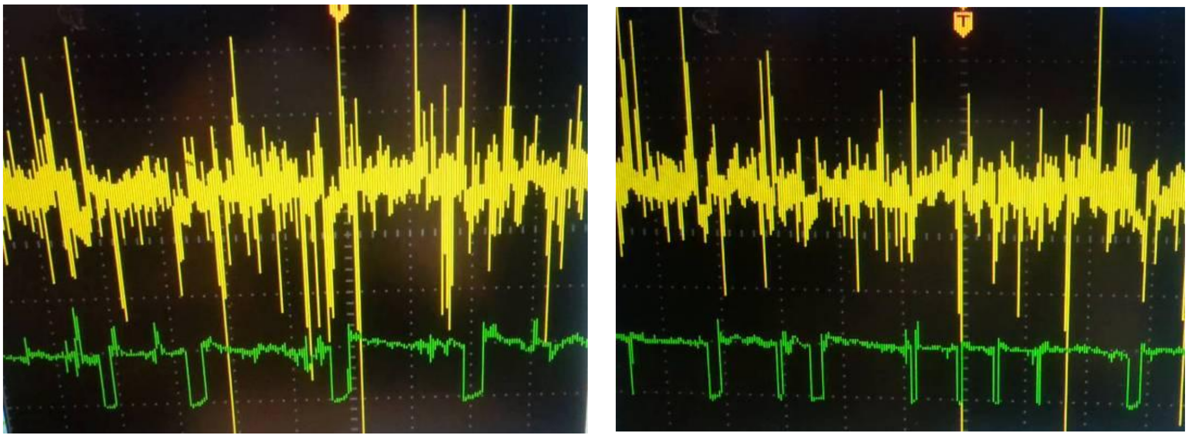
Consumption, l/min	Calculated gas rate, m/s		Experimentally obtained gas rate, m/s	
	Traditional	Double-jet	Traditional	Double-jet
10	0.97	2.02	0.94	1.96
20	1.93	4.05	1.83	3.95
30	2.89	6.07	2.7	5.82

Having compared calculation and experimental data, relative error was revealed not to exceed 10%, the developed model for calculation of shielding gas flow from the nozzle provides appropriate accuracy when solving tasks of steady-state reaction of axially symmetrical jet of shielding gas with the environment (volume consumption is different) [16, 17].

The determination of the influence of shielding gas flow rate on chemical composition of weld metal in consumable electrode welding in CO_2 required a fill-scale experiment. When experimenting, a weld bed was made on a 10 mm steel 40X plate by filler wire Sv-08G2S with diameter 1.2 mm in shielding gas CO_2. One-jet (conic nozzle) and double-jet gas shielding were used for welding a weld bed. Welding mode: I=150 A, arc voltage U = 24 V, filler wire extension L=12 mm, consumption of shielding gas Q=20 l/min. The experiments were carried out in similar conditions and modes, the speed of welding V = 3.3 mm/s. The source of power supply VS-300B, welding machine VD–1500.

In the process of experiments oscillograms of electric current and voltage were recorded by digital oscillograph Agilent Technologies DSO1012A.

The oscillograms show there is an increase in the gas-dynamic impact on the drop of electrode metal, as well as in the transfer frequency of drops from the filler wire into the weld pool due to the growing rate of gas flow from the nozzle, whereas metallurgical processes get less intensive and it takes less time for the drop to be transferred into the weld pool (Fig. 2).



a) b)

Fig. 2. Oscillograms of electric current and voltage: a) traditional one-jet gas shielding; b) double-jet gas shielding

Tests were carried out to identify chemical composition of the deposited metal (Tabl. 3).

Table 3

Chemical tests of deposited metal

Mass concentration of elements, %					
C	Mn	Si	Fe	Cr	Ni
Traditional one-jet gas shielding					
0.12	0.92	0.23	97.89	0.42	0.10
Double-jet gas shielding					
0.12	0.85	0.20	97.98	0.41	0.10

The boiling temperature, as well as evaporation heat of manganese are the lowest ones (Tabl. 4) of all alloying elements in the chemical composition of filler wires. Therefore, in welding (filler wire Sv-08G2S) at approximate temperature 3300 K, it evaporates and oxidizes on the drop surface [13].

Table 4

Thermodynamic properties of elementary substances (normal conditions) in the chemical composition of filler wire [18]

Property	Substance					
	Mn	Si	Cr	Ni	Fe	C graphite
Density, g/cm^3	7.21	2.33	7.19	8.9	7.87	2.25
Melting temperature, K	1517	1688	2130	1726	1812	3820
Boiling temperature, K	2235	2623	2945	3005	3134	5100
Evaporation heat, kJ/mole	221	383	342	378.6	340	-

The increase in the flow rate and number of particles, reacting with the drop surface, results in high burn-out of silicon and manganese [2, 12, 13].

In welding with two-jet gas shielding the rate of gas flow is 2.1 times higher than with one-jet shielding in conditions of this experiment, so a lot of manganese is removed from the drop surface. Therefore, electrode metal with lower concentration of manganese is transferred into the weld pool. Increasing CO_2 consumption when welding leads to the decrease in manganese concentration in the drop in any conditions of gas shielding [12, 14].

A lot of researchers [1-5, 10, 13, 14 etc.] point out at more advantageous conditions for molten metal reaction with gases and slag even at the stage of a drop but not in the weld pool. It is stated in [13] specific surface of molten filler metal drops is 5-22 times more extended (relative to the size of drops) as against that of the weld pool, and the specific rate of their oxidation is approximately 39 times higher. In terms of the mentioned above a conclusion can be made it is chemical composition of weld metal that influences mainly the composition of filler metal drops. The change in chemical composition of weld metal results in modification of operational characteristics of a joint weld. Varying manganese concentration in weld metal has a significant effect on its plasticity and impact strength [12, 14, 18-19].

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 [2, 14, 16, 17].

Conclusion

To sum up, in consumable electrode welding in CO_2 the rate of gas flow from the nozzle has a significant effect on the drop transfer and chemical composition of weld metal. Accurately selected gas shielding method (double-jet shielding) and consumption of gas allows of controlling the filler metal transfer and chemical composition of weld metal, making the process of welding uninterrupted, and forming necessary properties of joint welds.

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