CONCLUSIONS

1. Technology of repair welding of damage in AEIC from magnesium alloy ML10 was developed, including EDT of welds to lower the level of residual welding stresses.

2. By the results of EDT of full-scale AEIC fragments with characteristic damage of the item reconditioned by repair welding, it is established that EDT allows eliminating residual stresses in the weld.

3. Experimental procedure was developed, on the basis of which the influence of charging voltage on magnetic field intensity at EDT of welded joints of magnesium alloy ML10 was studied.

4. It is established that at up to 200 V charging voltage EDT operator can perform not more than 1100 actions of electrodynamic impact per a working shift, and at the voltage of 500 V — not more than 100, that supports the production cycle of repair welding of AEIC from magnesium alloy ML10.

1. Stepanov, G.V., Babutsky, A.I. (2007) Modeling of stress relaxation under action of pulsed electric current of high density. *Problemy Prochnosti*, **2**, 113–120.
2. Antonov, Yu.A., Ragozin, Yu.I. (2001) Pulse method of residual stress relieving. *Fizika i Khimiya Obrab. Materialov*, **3**, 91–95.
3. Lobanov, L.M., Pashchin, N.A., Loginov, V.P. et al. (2007) Change of the stress-strain state of welded joints of aluminium alloy AMg6 after electrodynamic treatment. *The Paton Welding J.*, **6**, 7–14.
4. Lobanov, L.M., Pashchin, N.A., Cherkashin, A.V. et al. (2012) Efficiency of electrodynamic treatment of aluminium alloy AMg6 and its welded joints. *Ibid.*, **1**, 2–6.
5. Levchenko, O.G. (2010) *Occupational safety and health in welding engineering*. Kiev: Osnova.

PROCEDURE FOR CALCULATION OF DIMENSIONS OF NOZZLES IN WELDING USING TWO SEPARATE GAS JETS

V.M. BELOKON and **A.O. KOROTEEV**

State Institution of Higher Professional Education «Belarusian-Russian University», Mogilyov, Republic of Belarus

Advantages of the process of welding without short-circuiting with double gas shielding of the arcing zone are shown. The arc is shielded by argon, and the weld pool — by carbon dioxide gas, fed through two concentrically located nozzles. Calculation of arc radius in its largest cross-section was performed. Calculation of weld pool length allows determination of the diameter of nozzle for carbon dioxide feed. Application of higher welding parameters requires increasing the diameter of nozzles, which can be calculated by similar procedures.

Keywords: *arc welding, consumable electrode, shielding gases, separate jets, dimensions of nozzles, calculation procedure*

Gas shielded welding finds wide application in production of various structures. At that CO_2 welding or welding in its mixtures with oxygen, argon etc. are often preferred. Welding without short-circuiting with double gas shielding, i.e. welding arc is shielded by Ar and weld metal by CO_2 is presented to be promising method. This method allows significantly reducing losses for electrode metal spattering, expenses for cleaning of near-weld zone from spatters and shielding gas costs [1–4].

Main parameters of each jet of shielding gas were experimentally determined by a number of domestic and foreign researchers and recommendations were provided for selection of dimensions of welding torch nozzles [5 et al.].

The aim of the present work is a development of procedure for calculation and determination of dimensions of nozzles (for Ar and CO_2) in reversed polarity current welding with two radial jets of shielding gases.

An electric arc consisting of three areas (anode, cathode and column) is used as a power source in consumable electrode welding. The anode and cathode areas have small dimensions. Anode spot in Ar welding can cover the whole end surface of the electrode and transfer to its side surface. At that transfer of electrode metal takes place in a form of small drops or jet that has positive effect on process of the electrode metal transfer, reducing spattering and splashing.

Argon shield of the cathode and anode areas, as well as arc column, can provide welding process, connected with positive effect of arcing in argon in welding with two concentric gas flows.

Putting of arc column to homogeneous channel with uniformly distributed within it tempera-

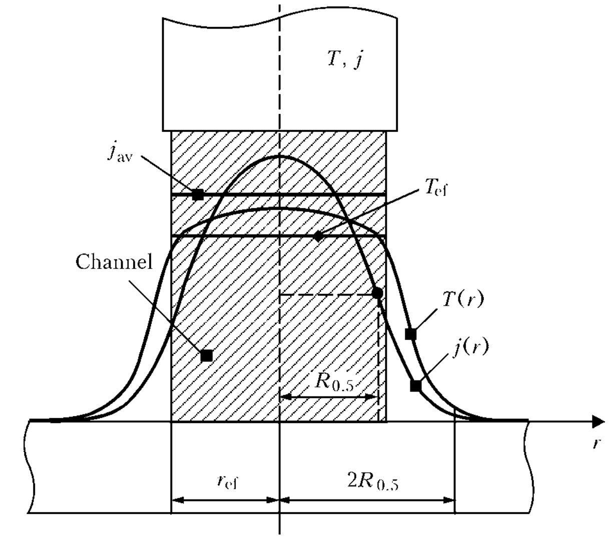

Figure 1. Scheme of «channel» model of arc column: r_{ef} — arc effective radius; j_{av} — average density of arc current; T — average effective temperature of arc; $R_{0.5}$ — conventional radius of arc column

ture and current is a reasonable idealization being sufficiently close to practice and does not violating the main physical representations in series of assumptions, considering that welding arc burns in iron vapors (in steel welding). Figure 1 shows the accepted scheme known as «channel» model of arc column [6, 7]. According to this model an average current density in the arc is distributed along the section with effective radius r_{ef}.

The average current density based on «channel» model is determined on formula

$$j_{av} = 5.5\cdot10^{-8}\,\frac{U_i^{38/12}a^{2/3}}{g_e^{2/3}I_a^{1/3}}, \qquad (1)$$

where U_i = 7.87 V is the ionization potential of metal vapors; a is the ratio of static weights of ions and atoms of iron vapors ($a^2 = 12/5$); g_e = = $35\cdot10^{-20}$ m^2 is the section of collision of atoms with electrons in Ar welding; I_a is the welding arc current, A.

Effective radius of arc column

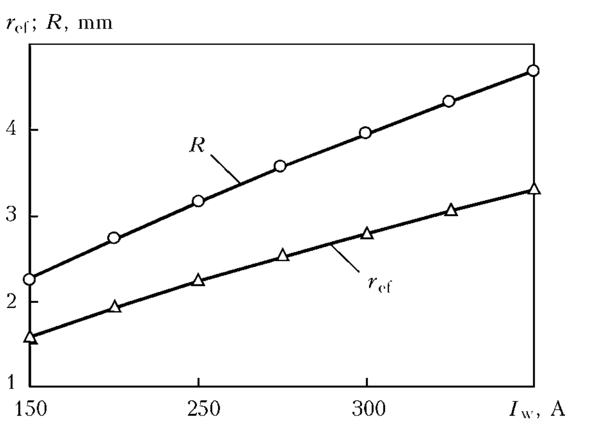

Figure 2. Dependence of effective r_{ef} and actual R radiuses of arc column on welding current

Table 1. Width of weld and active zone in welding using 1.2 mm diameter wire

Welding current, A	Arc voltage, V	Weld width, mm	Active zone width, mm	Dimension of active zone 2R acc. formula (5), mm
250	27	7.33	5.62	6.30
300	30	8.47	6.49	7.12
350	35	9.88	7.57	7.89
400	38	11.01	8.43	8.63

$$r_{ef} = \frac{\sqrt{I_a}}{\pi j_{av}} = \frac{2.4\cdot10^3 I_a^{2/3} g_e^{1/3}}{U^{19/12}a^{1/3}}. \qquad (2)$$

The whole arc current according to «channel» model passes through section with radius R determined on formula

$$R = 2R_{0.5}, \qquad (3)$$

where $R_{0.5}$ is the conventional arc radius related with effective radius by relationship

$$r_{ef} = 1.4R_{0.5}. \qquad (4)$$

The next will be obtained solving simultaneously expressions (2)–(4):

$$R = \frac{3.4\cdot10^3\, I_a^{2/3}\, g_e^{1/3}}{U^{19/12}a^{1/3}}. \qquad (5)$$

The results of calculation of effective and actual radius of the arc column depending on welding current intensity, represented in Figure 2, show that an internal nozzle feeding argon jet of around 9 mm diameter (R = 4.5 mm) is sufficient for complete shielding of welding arc from ambient environment by argon using normal welding modes (up to 450 A). The diameter of nozzle should be increased for welding modes of ≥450 A.

Shielding of welding arc only is obviously not enough for obtaining of quality weld. Shield of a surface of weld pool molten metal from interaction with atmosphere is necessary to be provided.

Table 2. Width of weld and active zone in welding using 1.6 mm diameter wire

Welding current, A	Arc voltage, V	Weld width, mm	Active zone width, mm	Dimension of active zone 2R acc. formula (5), mm
250	28	7.46	5.72	6.30
300	31	8.60	6.59	7.12
350	33	9.60	7.35	7.89
400	35	10.55	8.10	8.63
450	37	11.51	8.83	9.33

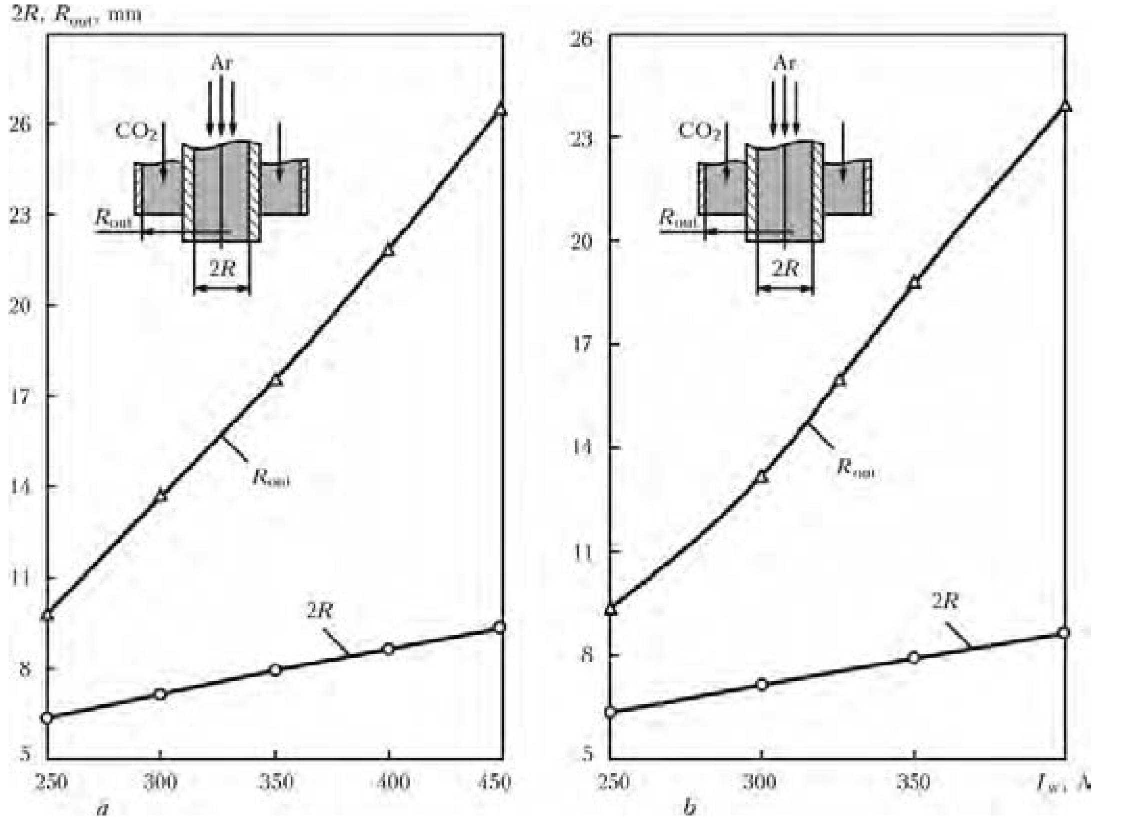

Figure 3. Dependence of dimensions of torch nozzles on welding current in welding using 1.2 (*a*) and 1.6 (*b*) mm diameter wire

The weld pool consists of specific zones. A central zone includes a head part of the weld pool and part of a tail. Cross-section of the central active zone, based on some sources, coincides with weld width [8]. In fact it is somewhat smaller.

Weld width can be determined on the following formula [9, 10]:

$$b = 2\sqrt{\frac{2q}{\pi e c\gamma v_w T}}, \quad (6)$$

where $q = \eta I_a U_a$ is the effective heat power of arc; U_a is the arc voltage, V; $\eta = 0.8$ is the efficiency; $c\gamma = 4.8$ J/(cm^3·K) is the volumetric heat capacity; v_w is the welding speed, m/h; T is the steel melting temperature, K.

Formula (6) can also be used for calculation of cross dimension of the weld pool active zone. For this temperature equal to metal evaporation temperature should be assumed in this formula. Calculation results show that the dimension of active zone virtually coincides with the actual dimension of arc column section, calculated on formula (5), through which all the arc current passes. Deviation makes not more than 5–10 %. Tables 1 and 2 show the results of calculation of the weld width and cross dimension of the weld pool active zone.

Weld pool length is determined on formula [10]

$$L = \frac{q}{2\pi\lambda T}, \quad (7)$$

where $\lambda = 47$ W/(m·K) is the coefficient of heat conductivity of steel.

Radius of outer nozzle for CO_2 feed, considering shield of surface of the weld pool from

Table 3. Results of calculation of weld pool length and radius of outer nozzle in welding using 1.2 mm diameter wire

Welding current, A	Arc voltage, V	Length of weld pool, mm	Radius of outer nozzle acc. formula (8), mm
250	27	13.07	9.40
300	30	17.43	13.20
350	35	23.73	18.79
400	38	29.44	23.94

Table 4. Results of calculation of weld pool length and radius of outer nozzle in welding using 1.6 mm diameter wire

Welding current, A	Arc voltage, V	Length of weld pool, mm	Radius of outer nozzle acc. formula (8), mm
250	28	13.56	9.82
300	31	18.01	13.71
350	33	22.37	17.58
400	35	27.12	21.84
450	37	32.25	26.50

interaction with atmosphere, can be calculated using formula

$$R_{out} = L - b/2. \quad (8)$$

Results of calculations are summarized in Tables 3 and 4.

Formula calculations show that application of 20 mm radius nozzles is enough for arcs with up to 350 A welding current and 1.2 and 1.6 mm diameter wires. Radius of the nozzle for outer gas jet should be larger in the case of welding with higher currents. The outer nozzle for the purpose of economy of shielding gas can be made in ellipse form, the cross dimension of which equals the weld pool and the longitudinal dimention equals its length.

The next sequence of calculation is proposed for welding torch nozzles: calculation of average current density in the arc column; determination of effective and actual radiuses of the welding arc; after that using values of these parameters determination of diameter of nozzle for argon feed (see Figure 2) and dimensions of the weld pool; determination of diameter of outer nozzle for CO_2 feed (Figure 3) considering the dimensions of active zone. Diameter of the outer nozzle can be reduced considering spreading of shielding gas flow in welding of flat joints [11].

Diagrams, shown in Figure 3, simplify the processes of practical fulfillment of the proposed procedure.

Analysis and calculations performed allowed determining the optimum relationship of shielding gases which should make 1:4, i.e. 20 % Ar and 80 % CO_2, from the general necessary consumption.

Primitive technical and economic calculations show that welding with two separate gas jets can be applied not only to special materials, but to low-alloyed as well as low-carbon steels. Economy only of electrode metal at that makes 20–95 kg per 1 t of wire that is character for pure argon welding without short-circuiting and it covers an insignificant increase of shielding gas consumption in comparison with CO_2 welding, welding with double and triple mixtures. Five time reduction of argon consumption is observed in comparison with pure argon welding.

CONCLUSIONS

1. Sequence and procedure for calculation of diameter of welding torch nozzle in welding with two separate jets of shielding gas is proposed. The optimum ratio of Ar and CO_2 in general consumption of shielding gas makes 1:4, i.e. Ar + + 80 % CO_2.

2. Calculation of diameter of nozzles for argon feed based on «channel» arc model was carried out, and calculation of dimensions of nozzles for CO_2 feed was performed considering the weld pool dimensions. It was determined that internal nozzle feeding argon jet of around 9 mm diameter is enough for welding in normal modes (up to 450 A).

1. Laevsky, V.S., Dyurgerov, N.G., Lenivkin, V.A. et al. (1969) Consumable electrode welding of low-carbon steels in combined shielding. *Svarochn. Proizvodstvo*, **10**, 21–22.
2. Potapievsky, A.G. (1973) *Consumable-electrode gas-shielded welding*. Moscow: Mashinostroenie.
3. Paton, B.E. (1974) *Technology of fusion arc welding of metals and alloys*. Moscow: Mashinostroenie.
4. Malyshev, B.D., Akulov, A.I., Alekseev, E.K. et al. (1989) *Welding and cutting in industrial engineering*. Ed. by B.D. Malyshev. Vol. 1. Moscow: Strojizdat.
5. Fedko, V.T., Kiyanov, S.S., Shmatchenko, V.S. et al. (2003) Application of double-jet nozzles for gas-shielded welding. *Avtomatizatsiya i Sovr. Tekhnologii*, **3**, 12–18.
6. Leskov, G.I. (1971) *Welding electric arc*. Moscow: Mashinostroenie.
7. Pavlyuk, S.K., Belokon, V.M. (1974) About stability of arc ignition process in consumable electrode welding. *Svarochn. Proizvodstvo*, **4**, 51–53.
8. Erokhin, A.A. (1973) *Principles of fusion welding*. Moscow: Mashinostroenie.
9. Akulov, A.I., Belchuk, G.A., Demyantsevich, V.P. (1977) *Technology and equipment for fusion welding*. Moscow: Mashinostroenie.
10. Petrov, G.A., Tumarev, A.S. (1967) *Theory of welding processes*. Moscow: Vysshaya Shkola.
11. Popravka, D.L., Khvorostov, N.E., Proskurin, V.N. (1973) Some principles of flow of shielded gas jet. *Svarochn. Proizvodstvo*, **6**, 33–36.