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The Analysis of Welding Conditions Under the Flux of Double-Sides Joints Without Edge Preparation

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Abstract: This paper represents the results of analysis for automatic welding conditions under the flux of double-sides butt joint without edge preparation. As the process characteristics, a specific energy of welding, joint formation rate, average weld width, fusion rate of base metal and other parameters were used. It is determined an optimal joint rate of about 1 cm^2/s, that can be used to calculate welding conditions. The paper founds the use of linear dependence between specific energy of welding and cross-section area of base metal's fusion.

Introduction

The analysis of automatic welding conditions under the flux of the butt joints is of interest to create adequate methods for calculating of optimal welding conditions. As it is noted in [1], a learned method, which is represented in [2], is not meet modern requirements, because it is based on the calculation of the heat transmission from a point heat source, which is active on the surface of semi-infinite body. The conditions of double-sides welding do not fully correspond to this scheme, because they do not consider the influence of the unit thickness and the distribution of a heat source to the fusion of the unit. In our opinion, the calculating method of welding conditions should consider patterns to energetic characteristics of the process. From these positions, this paper researches the welding conditions, which are typical for double-sides joint described in [1, 3].

Research Methods

We study energetic characteristics and parameters of fusion efficiency of base metal described in [1, 3]. Source data for welding conditions are shown in the Table 1. Parameter marks of common use for welding engineering are used in this table.

Table 1

Reference	δ, [mm]	d_e, [mm]	U_a, [V]	I_a, [A]	V_w, [cm/s]	V_e, [cm/s]
[1]	20	3.0	39.5	680	1.1	5.25
[1]	20	3.0	44.0	850	0.69	7.83
[3]	16	4.0	32.0	712	0.67	2.80

Experimental geometrical characteristics of welds, defined by the photos of macro sections with a help of today's software, are shown in the Table 2.

Table 2

I_a, [A]	Weld width B, [mm]	Penetration H, [mm]	F_O, [mm^2]	F_f, [mm^2]
712	20.0	9.5	115	52
680	17.0	8.5	58	29
850	22.0	13.9	142	78

Herewith, found cross section areas of base metal F_O and filled metal F_f are completely different from data in [1]. The area of filled metal on arc current I_a= 680 A was concurred both for the calculation on the speed of electrode fusion, and on the dimension of areas on micro-sections. The following data were calculated by experimental values:

1. Average width of fusion for base metal

$$B_a = \frac{F_O}{H}, \tag{1}$$

where H – penetration, mm.

2. Joint formation rate J

$$J = V_W \cdot H . \tag{2}$$

3. Specific energy of welding E [4].
4. Welding frequency [5]

$$f = \frac{F_O}{J} . \tag{3}$$

5. Specific consumption of fused base metal for joint formation

$$g_O = B_a \cdot \rho , \tag{4}$$

where ρ – density of base metal, for steel ρ=7.8 g/cm^3.

Besides, we calculate coefficients for fusion of base metal α_O, and electrode metal α_P, and thermic efficiency of the process η_t. For η_t a heat content of welding pool was taken as 7800 J/cm^3.

Results and Discussion

The calculation results are shown in the Tables 3 and 4.

Table 3

I_a, [A]	B_a, [cm]	J,[cm^2/s]	E, [kJ/cm^2]	f, [Hz]
712	1.21	0.64	2.95	1.8
680	0.68	0.94	2.37	0.62
850	1.02	0.96	3.23	1.48

Table 4

I_a, [A]	g_O, [g/cm^2]	α_O, [g/AHr]	α_P, [g/AHr]	η_t
712	9.44	30.9	14.5	0.32
680	5.30	26.3	13.9	0.23
850	7.96	32.4	18.7	0.25

In the Tables 3 and 4, data show that the most optimal condition is the second one for current I_a=680 A. Regarding to the first condition, the second one provides 1.5 times more joint rate J under the higher energy cost reduction E. It is proved by the minimal welding frequency f, which characterizes the efficiency of use of fused base metal on joint formation, as g_O does. The fusion coefficient of base metal α_O is approximately the same for all conditions. It is in average two times more then α_P, that is caused by the similar heat content reduction of welding pool's metal in comparison with the heat content of electrode metal. Herewith, it should be considered, that the second condition is not fully provide requirements for double-sides welding – the penetration of base metal should be at least 50% of thick. The first and the third conditions provide such requirement. For the first condition, the correlation of penetration to the thickness is H/δ = 0.59, and for the third condition it is H/δ= 0.65. The joint rate J ≈1.0 cm^2/s for the second and the third conditions can be a reference point for optimal welding conditions of different thickness.

The important index of the weld is a fusion area of base metal, which is difficult to be defined. Together with the cross-section area of filled metal, F_O influences on a part of base metal in a weld ψ_O. For the data shown in the Table 1, a linear dependence of fused area of base metal was selected

$$F_O = K\frac{q_e}{V_w\delta}, \tag{5}$$

where q_e – effective arc power, kW, K – coefficient.

A quantity q_e/δ was called a specific effective power, i.e. effective power, which suits on the welding thickness unit. Its calculation can be useful for welding of double-sides welds. For example, with the help of specific effective power a fused area of base metal can be estimated with a help of the calculated scheme of linear heat source. So, $q_e/V_w\delta$ can be called as specific running energy of welding.

An effective power of arc was calculated by the values of effective efficiency η_e=0.829, described in [6].

The values of K, comparison of calculated F_{OC} and experimental F_O cross-section areas of base metal, which were found by the formula (1), are shown in the Table 5.

Table 5

q_e, [kW]	K, [cm^4/kJ]	F_O, [cm^2]	F_{OC}, [cm^2]	Δ,[%]
15.11	$8.3\cdot10^{-2}$	1.17	1.06	-9.4
18.66	$6.8\cdot10^{-2}$	0.58	0.64	+10.3
26.50	$7.4\cdot10^{-2}$	1.42	1.40	-1.4

The average value of K_a=7.5 cm^4/kJ. The average on absolute value and relative deviation of calculated data from the experimental ones is 7% that is fully acceptable for engineering calculations. To use the formula (5) for calculating of welding conditions, it is necessary to study the dependence of specific welding energy E of one weld from the welded thickness.

To switch to the particular welding conditions, it is necessary to use the formula of arc voltage in [2]

$$U_a = 20 + 0.05\frac{I_a}{(d_e)^{0.5}} \pm 1. \tag{6}$$

For the studied welding conditions, the calculation of arc voltage on formula (6) shows good coincidence of these conditions according to [2] and deviation of + 18% according to [3].

To determine the penetration area of the base metal, the most prospective is the use of the formulas of heat transfer in welding [7]. For arc welding by a consumable electrode, the penetration of the base metal depends on the polarity of the arc. At the same time, the effective arc power does not depend on the polarity. In [8] this is explained by the influence of the liquid interlayer under the arc. Our hypothesis is that the power, transmitted by a consumable electrode to the product, affects the penetration differently than the arc power [9].

Based on this, a technique for calculating the penetration area of the base metal is proposed. This technique is the following. From the total effective arc power, it is necessary to take the power, transferred to the welding pool by the electrode metal. For testing were used the experimental data on the determination of the penetration while welding under the flux, given in [3]. To calculate thermal cycles using the equivalent heat source method, the volume heat capacity $c\rho$=4.5J/(cm^{3o}C), the thermal conductivity λ=0.32 W/(cm ºC) was assumed in [3]. It gives the temperature conductivity coefficient a=0.071cm^2/s. In this mode, it has been obtained a cross-section of the penetration on the macro section with a weld width of B=20 mm and a penetration of h=9.5 mm. With the help of modern software, the areas of penetration of the base metal F_O=1.17 cm^2 and the filled metal F_f = 0.52 cm^2 were measured.

The effective power was determined by adopting the effective arc efficiency under the flux with the same mode, η_e=0.829, according to the data of [6]

$$q_e = 0.829 \cdot 22784 = 18888 \text{ W}.$$

Using the formula for a normal-circular heat source [7], the penetration area of the base metal was first determined by a known technique, using the total effective arc power. To do this, the maximum width of the welding pool in sections along the thickness of the plate with a step of 1 mm was calculated with a help of special software in BASIC. Based on the obtained dimensions, a transverse profile of penetration of the base metal was built.

By the value of the effective power q_e and the experimental value of the penetration, the diameter of the heating spot of a normal-circular heat source D_H =1.34cm was determined. Therewith, the axial heat flow was q_M=40000 W/cm^2, and the heat flow concentration factor was k=6.63 cm^{-2}. The maximum calculating penetration at y=0 was H_M=9.43 mm, which differs from the experimental value by only 0.07 mm. The large value of q_M corresponds to the data obtained in [10], and it is due to the immersion of the arc in the welding pool under the arc pressure.

Fig. 1 (curve 1) shows the total calculated profile of penetration of the base metal. According to it, the average penetration was H_a=0.66 cm, and the calculated penetration area of the base metal is F_O=146 mm^2. The deviation of the calculated value of the area from the experimental value is 146-117 = 29 mm^2, which is 25%.

As before, by the proposed technique for reversing polarity of the arc, the penetration area of the base metal was determined. The power q_{MA}, transferred to the weld by the electrode metal anode, was determined too.

According to the [9], the voltage equivalent of the electrode power of the anode with the heating of the stick-out, is U_e= 5.3 W/A. So,

$$q_{MA} = 5.3 \cdot 712 = 3774 \text{ W}.$$

The power for usage in calculating of the penetration of base metal is

$$q_O = q_e - q_{MA} = 18888 - 3774 = 15114 \text{ W}.$$

When calculating the penetration of the base metal, the diameter of the heating spot D_H=1.34 cm was kept. For this effective power, an axial heat flow q_M =32000 W/cm^2, and a concentration coefficient k=6.63 cm^{-2} was obtained. The maximum calculated penetration at y=0 was H_M=8.18 mm, the average penetration was H_a = 0.57 cm, the cross-section area of the base metal was F_O=113 mm^2 (curve 2 in Fig. 1). The deviation from the experimental value of the area is 113-117= 4 mm^2, which is -3.4%, that is approximately 7 times more accurate than the known method provides.

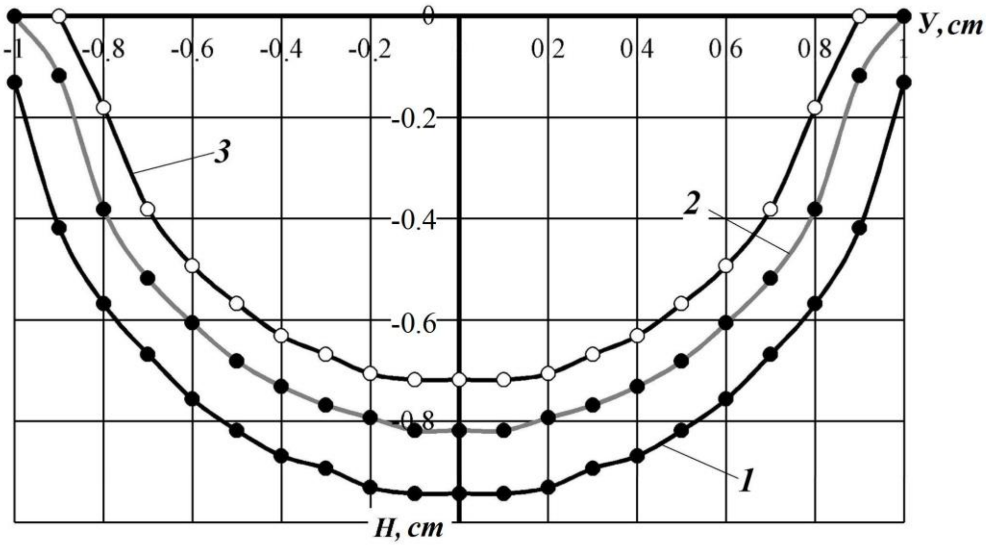

Fig.1. Calculated profiles of the penetration:

1 – without polarity; 2 – reversing polarity; 3 – normal polarity

As before, the penetration area of the base metal was determined by the proposed technique for normal polarity of the arc. The power q_{MA}, transferred to the weld by the electrode metal anode, was determined too.

According to the [6], the voltage equivalent of the electrode power of the cathode with the heating of the stick-out, is U_e= 9.3 W/A. So, the power, transferred by electrode metal to the weld is

$$q_{MA} = 9.3 \cdot 712 = 6622 \text{ W}.$$

The power for usage in calculating of the penetration of base metal is

$$q_O = q_e - q_{MA} = 18888 - 6622 = 12266 \text{ W}.$$

When calculating the penetration of the base metal, the diameter of the heating spot D_H=1.34 cm was kept. For this effective power, an axial heat flow q_M=25000 W/cm^2 was obtained. The maximum calculated penetration at y=0 was H_M=7.18 mm, the average penetration was H_a = 0.50 cm, the calculated penetration area of the base metal was F_O= 91 mm^2 (curve 3 in Fig. 1). The deviation from the experimental value of the area, obtained on the reversing polarity is 91-117= -26 mm^2, which is -22%.

The ratio of the obtained penetration areas of the base metal corresponds to the relations of penetrations in [2], depending on the polarity of the arc.

Conclusion

1. Optimal welding condition for one run from double-sides weld should be chosen considering available data about optimal joint rate, which is about 1.0 cm^2/s, and considering characteristics of efficient use of fused base metal.
2. The idea of dependence of fusion area for base metal of double-sides weld's one run, which is proportional to specific running energy of welding, is prospective.
3. The known methods for calculating the penetration of the base metal on welding by a consumable electrode, do not take into account the effect features on the electrode power process. It is most clearly seen when considering arc welding by a consumable electrode at different polarities.
4. Calculation of the penetration area of the base metal on welding by a consumable electrode should be carried out by reducing the effective power to power transferred to the welding pool by the electrode metal.

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