Definition of the Mathematical Model Coefficients on the Weld Size of Butt Joint Without Edge Preparation

Vladimir P Sidorov, Anna V Melzitdinova

Togliatti State University
445020, Volga Federal District, Samara region, Togliatti, Belorusskaya str., 14

E-mail: vladimir.sidorov.2012@list.ru

Abstract. This paper represents the definition methods for thermal constants according to the data of the weld width under the normal-circular heat source. The method is based on isoline contouring of "effective power – temperature conductivity coefficient". The definition of coefficients provides setting requirements to the precision of welding parameters support with the enough accuracy for an engineering practice.

Introduction

Automatic welding of thicknesses without edge preparation takes an important place in total welding work content. The issues of welding conditions optimization and improvement of quality for these joints are in priority. The most prospective way is to solve the arising problems with a help of mathematical methods, available in engineering practice.

Research Methods

This paper studies the prospects of use the analytic model of the normal-circular heat source on the surface of flat layer [1, 2] for improving the technology of argon arc welding. There were studied the experimental data for weld width in a work [3], in which it is described the welding for butt joints made of steel 12X18H9T of 1.5; 2; 3 mm thick on a cooper backing with a slot. The facing weld width $E1$ and the turning roll width $E2$ were measured. Experiments in the work [3] were conducted under the changing of welding speed V_w for several arc current I.

As a basis for analysis we study the results for the thickness of δ = 3mm with the arc length of L_a = 3 mm. Despite of intensive experiment performance, there was a significant unit variation of results, which rises up to 10% from the average values. This instability can be described by the influence of surface phenomena on the metal spreading of welding pool on the weld border.

It was found that the dependencies of weld width from weld speed are hyperboles. According to this fact, the data of [3] were processed by known software [4], and coefficients of hyperbolic dependencies were defined. Each dependency is for one current value and arc length value. It turned out that in absolute, the average relative deviations of the approximated data do not exceed 1% for facing weld width $E1$. For turning roll width $E2$ the deviations are slightly higher, but they do not exceed 4%. Figure 1 shows the example of approximating dependencies. These curves allow using not only experimental values, but any intermediate values for the analysis.
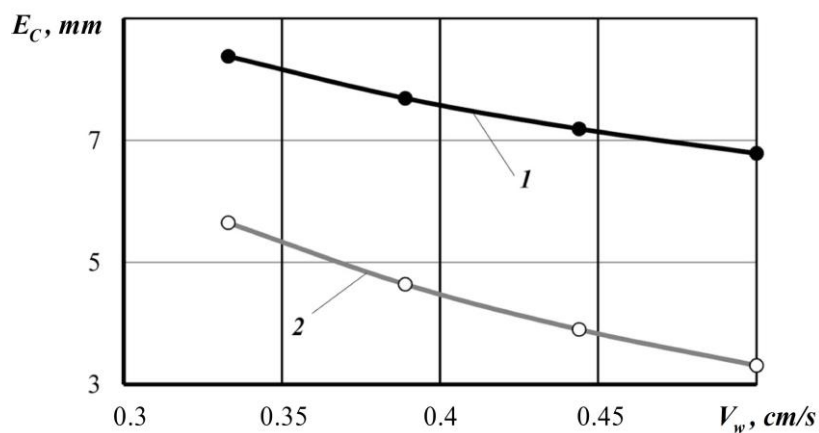
Fig.1. Calculated data of weld width based on the experimental points
1. For $E1$; 2. For $E2$. I_a= 190 A.l_a= 2 mm

It is natural to assume that approximating data, averaging the whole sets of experiments, in general better describe the real dependencies than the experimental points. Therefore, approximating data were further used for the analysis.

In [3] the weld parameter was calculated by numerical method considering the change of thermal constants on the temperature and a separation of heat source into two sources – the normal-circular heat source and the linear heat source with correspondence of their power of 0.8/0.3-0.8/0.2. According to the data in [3], the change of temperature conductivity coefficient a from the temperature was calculated. As a result, in temperature interval from 100ºC to 900ºC the coefficient a was rose from 0.04 cm^2/s to 0.07 cm^2/s. Figure 2 shows the calculation results.
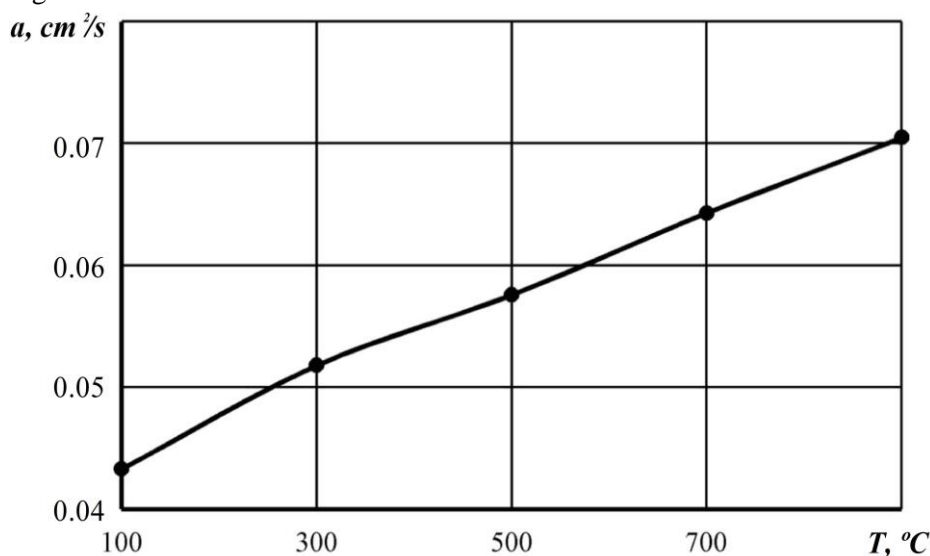

Fig.2. Dependency of a from the temperature for steel 12X18H9T

The temperature expression from the normal-circular heat source shows that the correspondence of effective power q_e and volumetric heat capacity $c\rho$ can be as one of the parameters of $Q = q_e /c\rho$. Then the influence of q_e and the temperature conductivity coefficient a on the weld size were calculated with $c\rho$ =4.5 J/(cm^{3}ºC).

To calculate the weld width, we developed a BASIC software program. A settling time for welding was 20 seconds, each of which was divided into 50 parts. A dichotomy method was used as a numerical

one [4,5]. The weld width along the X axis was defined with a space of 1 mm, and the calculation precision was 0.1 mm.

Results and Discussion

There were built dependencies of two experimental values for weld size $E1$ and $E2$ from q_e for several coefficients $\boldsymbol{a}$, which varied within the limits of dependency that is shown in Fig. 2. The values of $E1$ and $E2$ were chosen for average value of variation interval V_w. The example of such dependencies for $E1$ is shown in Figure 3.
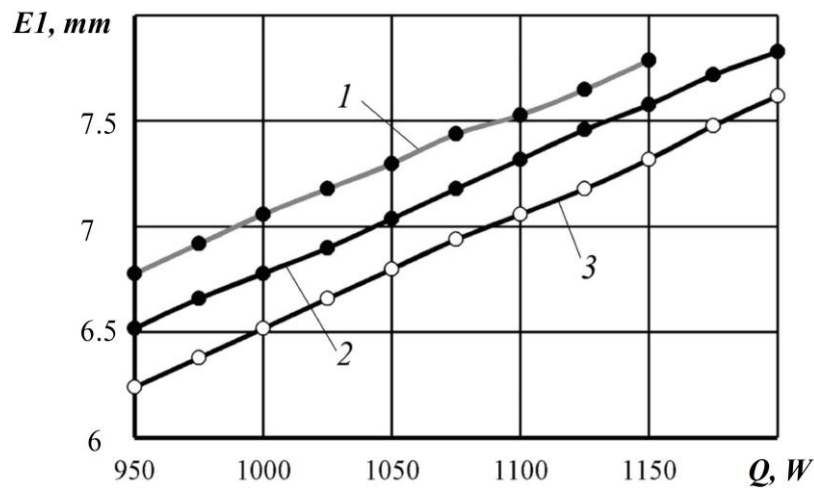

Fig.3. Series of width dependencies $E1$ from effective power
1. $a = 0.04$ cm^2/s; 2. $a = 0.05$ cm^2/s; 3. $a = 0.06$ cm^2/s.

Drawing a line, parallel to the Q axis, we obtain points to draw the isoline Q-$\boldsymbol{a}$.

The dependence of the calculated weld width $E1$ and $E2$ from q_e was plotted for three $\boldsymbol{a}$ values consequently for three values of axial heat flow q_O. Welding speed remained constant $V_w = 0.444$ cm/s. Fig. 4 shows the example of dependencies for $q_O = 3400$ W/cm^2.
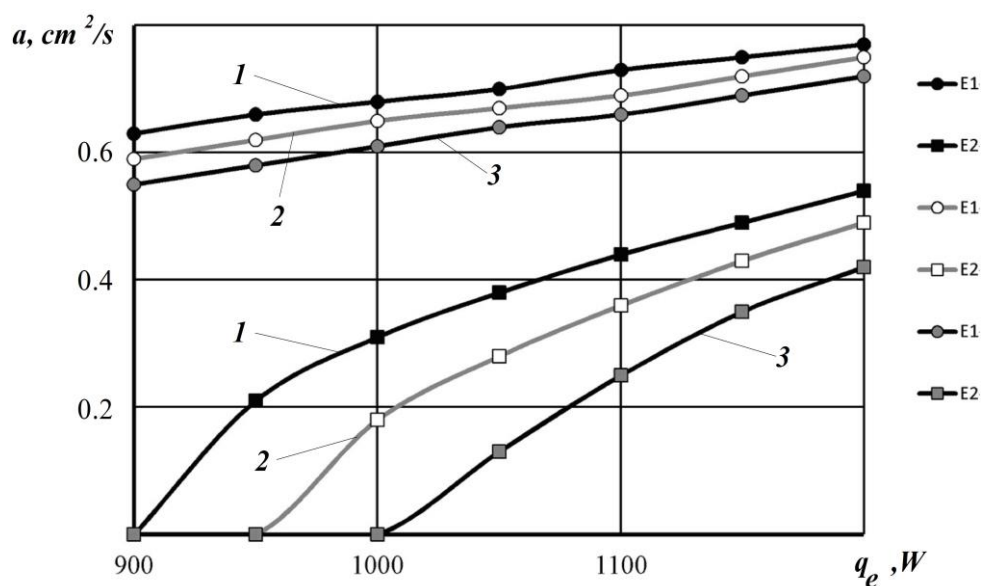

Fig. 4. Series of width dependencies $E1$ and $E2$ from effective power
1. $a = 0.04$ cm^2/s; 2. $a = 0.05$ cm^2/s; 3. $a = 0.06$ cm^2/s.

Curve for facing weld width and for turning roll width are completely different. On the studied conditions, the derivative dE/dq_e for the turning roll is much bigger, than for facing weld width. The feature is more pronounced in low power. In high power, the gradients become similar.

Experimentally taking the weld width values of $E1$=7.1 mm, $E2$=3.8 mm, we have isolines "q_e – temperature conductivity **a**" for two weld sizes (Fig.5, 6).
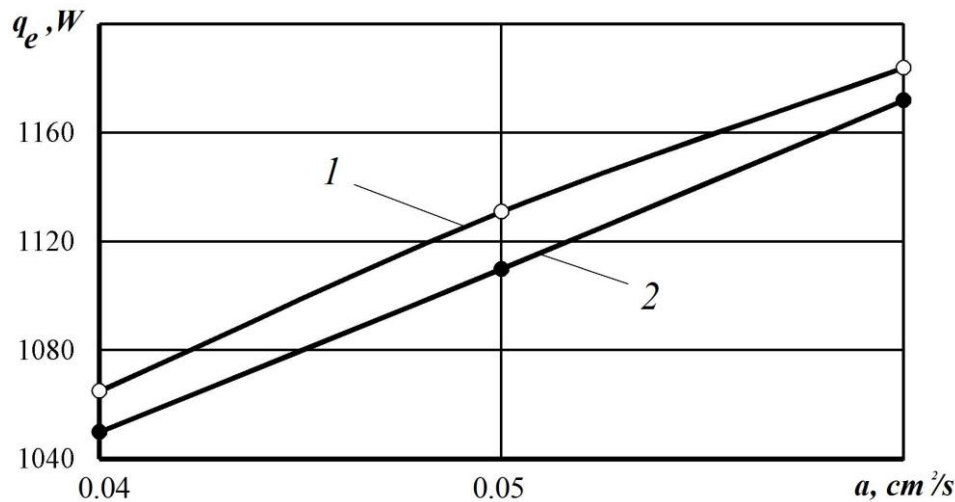

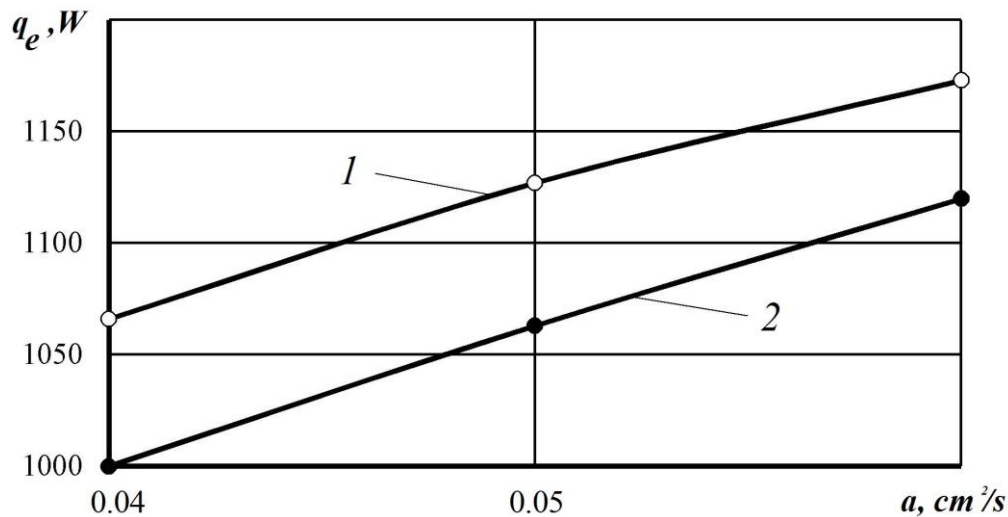Fig. 5. Isolines for weld sizes. 1 - $E1$; 2 - $E2$. q_O =3400 W/cm^2.

Fig. 6. Isolines for q_O =4200 W/cm^2. 1 - $E1$; 2 - $E2$.

Isolines on Fig. 3 for q_O =3400 W/cm^2 are closer to each other than isolines for q_O =4200 W/cm^2. Isolines for q_O =5000 W/cm^2 are much farer from each other. To define the model parameters, the isolines on Fig.5 were chosen. As there was not their cross point, the optimal parameter values were the average coordinate values of the segment of the minimal distant between the isolines. For Fig. 5 the value q_e = 1170 W, **a** = 0.059 cm^2/s. The Volt equivalent of effective power is 1170 W/190 A = 6.2 W/A. Effective efficiency $\eta_e \approx 0.62$. Diameter of heating spot on the studied condition was D_H = 1.15 cm, concentration coefficient of heat flow k=9.12 cm^{-2}.

According to these values, the weld sizes on nominal condition I=190 A, V_w =0.444 cm/s was calculated. The values of $E1$= 7.0 mm, $E2$= 3.9 mm were taken. The difference with experimental values

is 0.1 mm that concurs with the calculation precision of the weld width. It may be concluded that the model parameters were right.

After this, the resulting values q_O; **a** were used to calculate the weld width on the others arc current. The effective power was changed in proportion with a help of the Volt equivalent of effective power, which practically does not depend on the arc current. [5, 6, 7] Herewith, there were changes of the heating spot diameter D_H and the concentration coefficient of heat flow k. [8] The comparison of experimental and calculated data are shown in the Table.

Absolute and relative deviations for current values are shown in the Table.

Table

Weld width , deviation	I=170 [A]		I=210 [A]		I=225 [A]	
	Experiment	Result	Experiment	Result	Experiment	Result
$E1$, [mm]	6.5	6.2	8.2	7.7	8.2	7.6
$\Delta E1/E1$, [%]	-4.6		-6.1		-7.3	
$E2$, [mm]	2.5	1.6	4.4	5.4	4.7	4.8
$\Delta E2/E2$, [%]	-36.0		+22.7		+2.1	

Note: for current $I = 225$ A the welding speed $V_w = 0.5$ cm/s.

Data from the Table show that resulted values q_e and **a** are well description of the facing roll width in a range of ±15%, that differ from the turning roll width. Obviously, it is connected to the fact that the welding was on a cooper backing. Also an intensive heat removal from the back surface influences on the result.

Conclusion

1. The methods of definition for three mathematical model coefficients of normal-circuit heat source on two weld width values were developed. These coefficients are the correspondence of effective power to volumetric heat capacity of parts, temperature conductivity coefficient and axial heat flow.
2. Calculated data for turning roll width are two times inaccurate then the difference of experimental data. Herewith, to define the relative deviations of welding conditions for turning roll, this method should be used for experimental data on the turning roll width.

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