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APPROXIMATE CALCULATION OF RADIUS OF WELD TRANSITION TO BASE METAL OF WELDED BUTT JOINT ACCORDING TO NORMALIZED PARAMETERS

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The aim of the present work was to establish mathematical dependencies between geometric parameters of welded bead, taken into account the stress concentration factor in welded butt joints and standard parameters of height and width of weld reinforcement during calculation. It was suggested to describe fillets and a convex part of the reinforcement of a welded butt joint in the form of arcs of contacting circumferences, which allowed establishing the functional relation between the side angle and the height-to-width ratio of the reinforcement. Using this relation, the values of the height-to-width ratio of the reinforcement and the values of radius of weld transition to base metal, corresponding to them, were determined on the basis of the known dependences of this radius on the side angle for different types of fusion welding. By plotting the regression dependencies using the computer-aided design system MathCAD, the mathematical formulas were obtained to determine the radius of weld transition to base metal through the height-to-width ratio of the butt welded joint produced by submerged arc welding and welding in shielding gases. 13 Ref., 3 Tables, 3 Figures.

Keywords: *welded butt joint, stress concentration, weld geometry, radius of weld transition to base metal, side angle, normalized parameters, approximate calculation*

The stress concentration, caused by geometrical heterogeneity of welded joints, is one of the main factors determining their fatigue resistance [1]. For a quantitative evaluation of this phenomenon, as a rule the stress concentration factor (SCF) is used, which depends primarily on such parameters of the welded joint geometry as the radius of weld transition to base metal r and the side angle θ [2], however, the standards on welded joints (GOST 14771–76, GOST 8713–79, GOST 14806–80 and GOST 5264–80) do not regulate these parameters. Therefore, establishing the relation between the radius of transition and side angle with the normalized parameters of height h and the width g of the reinforcement remains an urgent problem for today in the field of practical calculations for strength, reliability, and durability of welded joints and structure elements.

The value of radius of weld transition to base metal depends on many factors, in particular, on welding mode and thermophysical properties of the metal joined, surface tension of weld metal and purity of surface of the elements joined [3].

In general form, this dependence is presented in the work [4] as follows:

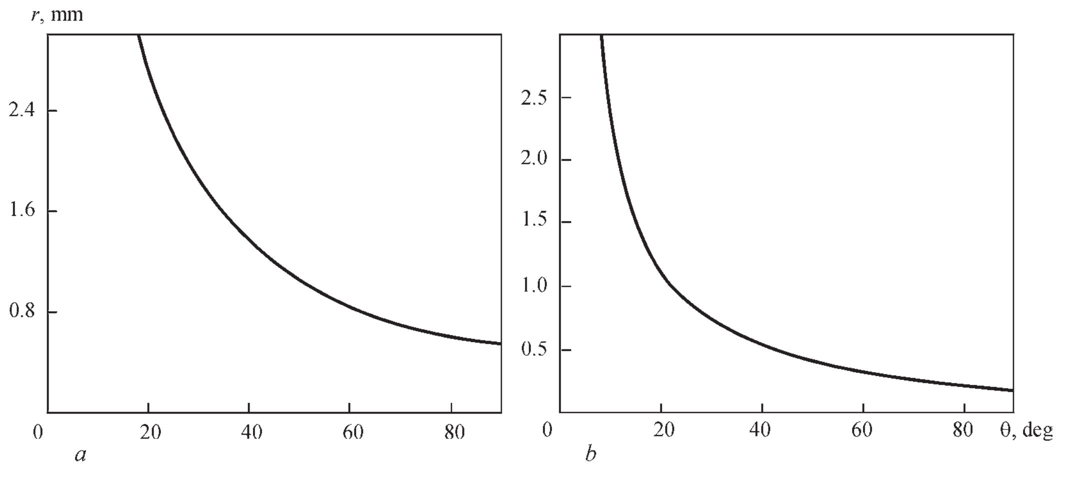

Figure 1. Diagrams of dependence of radius of weld transition to base metal from side angle for welded joints, made by submerged arc welding (*a*) and welding in shielding gases (*b*)

Table 1. Dependence of radius of weld transition to base metal for different values of side angle

Side angle (θ), deg		90	80	70	60	50	40	30	20	18	10	8
h/g		0.5	0.42	0.35	0.29	0.23	0.18	0.135	0.09	0.08	0.045	0.035
$(h/g)^{1/2}$		0.707	0.65	0.59	0.54	0.48	0.424	0.367	0.3	0.283	0.212	0.187
Transition radius r, mm for type of welding	Submerged	0.55	0.6	0.7	0.83	1.05	1.37	1.85	2.7	3.0	–	–
	In shielding gases	0.18	0.22	0.27	0.33	0.41	0.54	0.74	1.10	–	2.31	3.0

$$r = f_1\left(\frac{h}{g}\right) + f_2\left(T_0\right) + f_3(\sigma) + f_4\left(R_z\right), \qquad (1)$$

where f_1–f_4 are the terms taking into account dimensions of the reinforcement, initial temperature of welded plates, surface tension of the weld metal and roughness of surface of elements joined.

In the work [4] it was proved that the initial temperature and surface purity have a comparatively small influence on weld formation and the surface tension changes in the narrow interval and its influence can also be neglected. Therefore, the terms f_2–f_4 as compared to the term f_1 are the values of the second order of smallness. Hence, if the other conditions are equal, the first factor has a primary importance, and in the first approximation the radius of transition depends on height and width of the reinforcement, since they determine the ratio *h/g*. Therefore, the aim of the present work is to find this dependence in the form of a mathematical formula.

All the parameters of weld convexity profile, predetermined by welding process, are interrelated. Thus, the transition radius and side angle are related by dependence of the form [5]

$$r = f(1/\theta). \qquad (2)$$

The existence of such dependence is confirmed by experimental measurements of geometry of welded joints produced by different types of fusion welding in the zones of weld transition to base metal (Figure 1) [6].

Here, the side angle can be unambiguously determined through the height and width of the reinforcement if the shape of convexity is described by parabola [7], by circumference arc [8], or other more complex integral or differential dependence [9, 10].

In the present work it is proposed to describe the shape of reinforcement in the form of arcs of the contacting circumferences (Figure 2), then, the side angle will be determined through the ratio *h/g* by the dependence

$$\theta = 2\arctan\frac{2h}{g}. \qquad (3)$$

Having expressed the ratio *h/g* from the formula (3), it is possible to determine its values for different values of side angle, and the values of radii of weld transition to base metal, corresponding to these values (Table 1), by using the diagrams (Figure 1).

On the basis of discrete data, the system of the computer-aided design MathCAD allows plotting the regression dependence of one value from another in the form of a polynomial of the *n*-th power, where *n* is a positive integral number [11]. However, since in the given case (Table 1) the ratio *h/g* takes the values differing from each other by more than an order, then it is rational to seek the dependence of the radius of weld transition to base metal on this parameter in the form of a polynomial with fractional degrees

$$r\left(\frac{h}{g}\right) = \sum_{i=0}^{n} a_i \left(\frac{h}{g}\right)^{\frac{1}{2}}, \qquad (4)$$

where a_i are the factors of regression function.

By successive increasing the number of terms of the approximating series (4), it was established that for the case of submerged arc welding, the deviation of the experimental results (Table 1) from the results of calculation, according to the formula with retention of the first five terms of this series,

$$r\left(\frac{h}{g}\right) = 15 - 77.64\left(\frac{h}{g}\right)^{\frac{1}{2}} + 166.7\left(\frac{h}{g}\right) - 168.45\left(\frac{h}{g}\right)^{\frac{3}{2}} + 66.6\left(\frac{h}{g}\right)^{2} \qquad (5)$$

amounts to not more than 0.43% (Table 2).

The investigation of function (5), according to the well-known method [12], showed that it decreases in a strict monotonous way at the interval of changes in the ratio *h/g* from 0 to 0.5 (Figure 3, *a*).

For the case of welding in shielding gases, it was established that deviation of the calculated values of transition radius according to the formula, obtained by retention of the first seven terms of the series (4) from the experimental results (Table 1), amounts to not more than 1.212 % (Table 3).

The investigation of function (6) showed that, similar to the function (5), it decreases in a strict monotonous way at the interval of change in the ratio *h/g* from 0 to 0.5 (Figure 3, *b*).

Thus, using the formula (3), as well as the formulae (5) or (6), depending on welding method, having

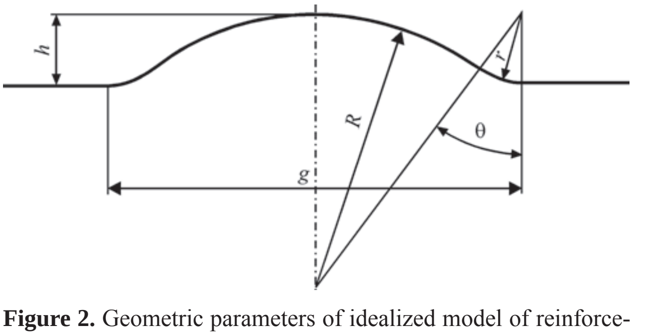

Figure 2. Geometric parameters of idealized model of reinforcement on one of the sides of welded butt joint, made by fusion welding

Table 2. Experimental and calculation values of radius of weld transition to base metal of the butt joint, made under the flux

h/*g*	0.5	0.42	0.35	0.29	0.23	0.18	0.135	0.09	0.08
Measured transition radius, mm	0.55	0.6	0.7	0.83	1.05	1.37	1.85	2.7	3.0
Calculated transition radius, mm	0.55	0.601	0.697	0.832	1.053	1.368	1.847	2.709	2.994
Deviation, %	0	0.17	0.43	0.24	0.29	0.15	0.16	0.33	0.20

Table 3. Experimental and calculation values of radius of weld transition to base metal of the butt joint, made in shielding gases

h/*g*	0.5	0.42	0.35	0.29	0.23	0.18	0.135	0.09	0.045	0.035
Measured transition radius, mm	0.18	0.22	0.27	0.33	0.41	0.54	0.74	1.10	2.31	3.0
Calculated transition radius, mm	0.18	0.219	0.272	0.326	0.413	0.542	0.735	1.103	2.308	3.001
Deviation, %	0	0.45	0.74	1.21	0.73	0.37	0.68	0.27	0.09	0.03

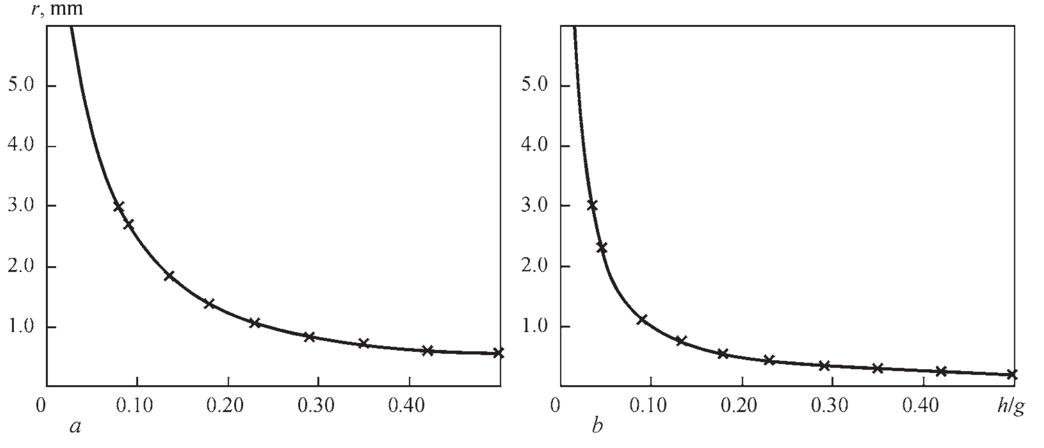

Figure 3. Diagram of dependence of radius of weld transition to base metal on height-to-width ratio of reinforcement and experimental points (×) for butt welded joint made by submerged arc welding (*a*) and welding in shielding gases (*b*)

the parameters of height and width of the reinforcement regulated by the standards, it is possible to establish all the geometric characteristics, necessary for determination of the SCF value in butt welded joints according to the known calculated dependences [13].

Conclusions

1. An idealized model of the shape of butt weld reinforcement was proposed, according to which the curve, formed by the fillets and a convex part of the reinforcement is described by arcs of contacting circumferences. The use of the proposed model allows an unambiguous determination of the side angle as a continuous function of height-to-width ratio of the reinforcement.

2. By approximating the discrete data with polynomials with fractional powers, using the system of the computer-aided design MathCAD, the mathematical formulae were obtained for determination of the radius of weld transition to base metal through the height-to-width ratio of the reinforcement of butt joint, made by submerged arc welding and welding in shielding gases.

1. Trufyakov, V.I., Dvoretsky, V.I., Mikheev, P.P. (1990) *Strength of welded joints under alternating loads*. Kiev: Naukova Dumka.
2. Knysh, V.V., Klochkov, I.N., Pashulya, M.P. et al. (2014) Increase of fatigue resistance of sheet welded joints of aluminum alloys using high-frequency peening. *The Paton Welding J.*, **5**, 21–27.
3. Belchuk, G.A., Naletov, V.S. (1972) On some dependencies of weld formation in zone of weld-base metal junction. *Svarka v Sudostroenii*, **79**, 32–35.
4. Belchuk, G.A. (1969) *Welded joints in hull structures*. Leningrad: Sudostroenie.
5. Shonin, V.A., Poklyatsky, A.G. (2001) Low-cycle fatigue of welded butt joints made from alloy AMg6 in inert atmosphere. *The Paton Welding J.*, **3**, 18–22.
6. Berezovsky, B.M., Stikhin, V.A. (1981) Peculiarities of transition zone formation from butt weld reinforcement to base metal. *Voprosy Svarochn. Proizvodstva*, **266**, 99–106.
7. Belchuk, G.A. (1964) *Approximate calculation of geometric shape and stress concentration coefficient of welded butt joints on welding mode*. Leningrad: LDNTP.
8. Kaufmann, P. (1970) Ermuedungsverhalten von Stumpfnaehten. *Schweisstechnik*, 20(**1**), 38–41.
9. Patskevich, I.R., Ryabov, V.R., Deev, G.F. (1991) *Surface phenomena in welding of metals*. Kiev: Naukova Dumka.
10. Pankov, V.V., Pankov, S.V., Bogorodsky, I.G. et al. (2015) Measure function of weld as the basis in development of digital technologies of weld quality. *Zh. Neftegazovogo Stroitelstva*, **2**, 20–26.
11. Alekseev, E.R., Chesnokova, O.V. (2006) *Solution of problems of computational mathematics in packets Mathcad 12, MATLAB 7, Maple 9*. Moscow: NT Press.
12. Bugrov, Ya.S., Nikolsky S.M. (2004) *Higher mathematics*: Manual for inst. of higher education. Moscow: Drofa. Vol.2: Differential and integral calculus.
13. Makhnenko, V.I., Mosenkis, R.Yu. (1985) Calculation of stress concentration coefficients in joints with butt and fillet welds. *Avtomatich. Svarka*, **8**, 7–18.

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