SELECTION OF THE GROOVE SHAPE FOR REPAIR OF THROUGH CRACKS BY MULTILAYER ELECTROSLAG WELDING

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The article gives results of calculation of the groove shape and penetration depth for repair of through cracks in thick parts by multilayer electroslag welding.

Keywords: *multilayer electroslag welding, carbon steels, band of cement kiln, through crack, repair, groove shape, gap width, penetration depth, consumable nozzle, pitch of holes*

Application of electroslag welding (ESW) to repair cracks in large-sized thick-walled expensive machine and mechanism parts makes it possible to substantially reduce the terms of their repair operations, extend their service life and save money and materials [1, 2]. The method of multilayer electroslag welding (MESW) is used to repair failed parts directly in site of their operation, particularly under erection conditions. This method allows using simple mobile small-size equipment and low-capacity power supplies [3].

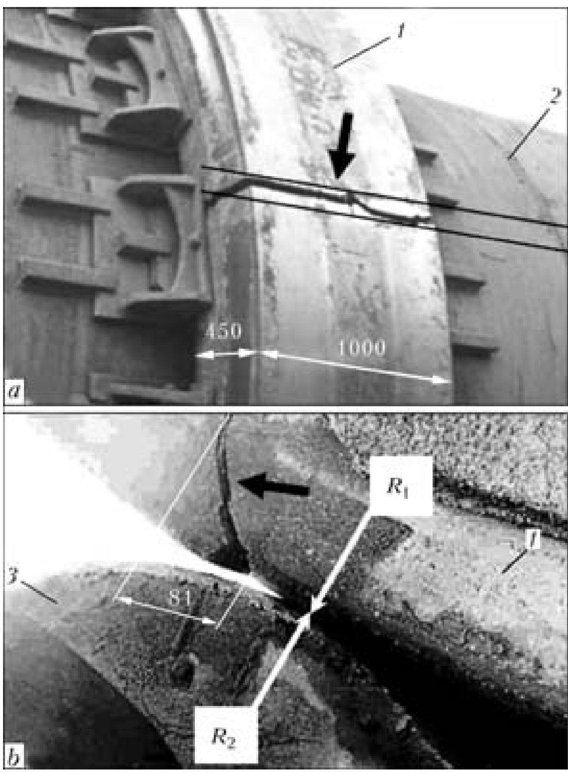

Figure 1. Through cracks in bands of rotary cement kilns 5 m in diameter: *a* — deviation of crack from the cross section plane of the band; *b* — deviation from the radial plane; *1* — band; *2* — kiln casing; *3* — bearing roller; R_1 = 3050 mm — radius of roll surface of band; R_2 = 450 mm — radius of bearing roller

A crack is grooved for welding with small regions (pits) by drilling 65–75 mm diameter holes at a pitch of 80–90 mm [4]. However, to repair through cracks having considerable branches, the shape of the groove and pitch of the deposited layers should be determined depending on the configuration and size of defects [5, 6]. For example, in repair of through cracks in bands of rotary kilns the deviations of a crack from the cross section plane may amount to 60–110 mm, and those from the radial plane — 40–100 mm (Figure 1), sizes of the failed sections being (355–500)×(900–1350) mm. High-quality grooving of such defects by drilling through holes [5] is hardly feasible, as it does not allow an entire defective region of metal to be removed. Therefore, the defective region with a crack is removed by machining or gas-oxygen cutting by making two through parallel cuts in a workpiece. The distance between the cut planes is selected such that it covers the whole crack region. Then steel plates are placed at a certain distance into the resulting gap, thus forming holes of a rectangular shape [6].

The optimal shape of the groove in MESW should provide a stable process, maximal productivity of repair, required depth and width of penetration of the base metal in the filled-in hole, guaranteed fusion of layers of the multilayer weld, and achievement of the maximal effect of auto-heat treatment with a heat released in deposition of the next layer.

Geometric parameters of the groove were calculated on the basis of the data obtained experimentally. ESW of 300–620 mm thick samples of steel 35L and 34L-ESh was performed by using units A-645, A-1304 and AShP 113M, as well as AC power supply TShS-3000-3. The use was made of 3 mm diameter electrode wires of the Sv-08GA and SV-10G2 grades and flux AN-8M. The holes made by installing the rolled metal plates were filled in sequentially by using the twin-electrode consumable nozzle at specific heat input q_w = = 70–175 kJ/cm^2. Transverse macrosections were made from the templates cut out from the welded samples in the planes normal to the multilayer weld.

The experience of repair operations shows that most often the width of the groove for filling-in of through cracks is 60–120 mm. The much larger width of the groove (welding gap) than in traditional ESW is attributable to the necessity to fully remove the workpiece metal located in the crack branching zone.

Width S_p of the filled-in hole (pit) formed by installing the shaping spacer plates (partitions) was determined as a function of two variables from the following relationship:

$$S_p = \frac{F_d}{B},$$

where F_d is the surface area of the deposited metal, and B is the width of the welding gap.

As shown by the data given in studies [3, 4, 7–10], as well as by additional experiments on filling-in of rectangular holes by the ESW method using the consumable nozzle, the satisfactory fusion of the base metal and metal of the shaping spacer plates can be achieved in the case of the groove with a cross section area of 2500 to 4500 mm^2. Figure 2 shows the diagram of optimal ratios of gap width B to pit width S_p for MESW with the twin-electrode consumable nozzle.

Examination of transverse macrosections of specimens with the holes filled in by MESW with the twin-electrode consumable nozzle indicated that at a ratio of groove width B to filled-in hole width S_p equal to 1.1–2.4 the penetration shape in a cross section is close to ellipse. Based on this observation, a scheme (Figure 3) was worked out to calculate the expected penetration shape in MESW. It can be seen from this scheme that to provide the good fusion of filler metal to edges of the base metal it is necessary to optimise the following parameters: local width of penetration of the base metal edges in the filled-in hole, S_b; distance between the axes of the filled-in holes (pitch), t; and width of a region of repeated penetration of the base metal edges in place of installing of the shaping spacer plate after deposition of the neighbouring layer, l.

Parameter S_b characterises part of thickness of the joint welded per pass by the MESW method.

The classic ellipse equation [11] was used to calculate the above parameters. This equation allows determining coordinates of points M (x, y) and N $(x, -y)$ of the chord parallel to one of the ellipse diameters (see Figure 3). Hence:

$$y = \sqrt{\left(1 - \frac{x^2}{a^2}\right) b^2}, \qquad (1)$$

where a and b are the ellipse semi-axes.

Expression (1) was used to determine the minimal required width of penetration of the base metal edges in the filled-in hole, S_b, for the preset depth of penetration of the base metal, h (see Figure 3).

By expressing the unknown value through $S_b = 2y$, and parameters x, a and b — through values indicated in Figure 3, and by making cancellations, we obtain that

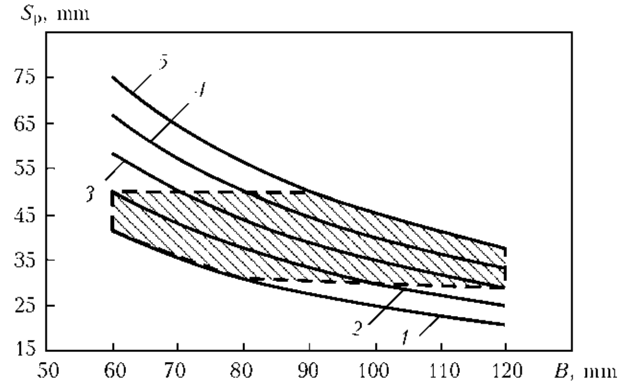

Figure 2. Range of optimal ratios of gap width B to pit width S_p for MESW with twin-electrode consumable nozzle: *1* — F_d = 2500; *2* — 3000; *3* — 3500; *4* — 4000; *5* — 4500 mm^2

$$S_b = 2\sqrt{\left[1 - \frac{B^2}{B^2 + 4h(B + h)}\right]\left(\frac{S_p}{2} + h_{pl}\right)^2}, \qquad (2)$$

where h_{pl} is the depth of penetration of the shaping spacer plate.

To reduce variables in formula (2), the diagram of the ratio of the base metal to shaping spacer plate metal penetration depth was plotted on the basis of experimental data (Figure 4). The approximated line of this diagram can be expressed in terms of a linear function [12]

$$y = mx + c, \qquad (3)$$

where m is the angular coefficient equal to tg α, and c = 13 mm

Substantiation of the m and c values taken from Figure 4 to equation (3) and replacement of the penetration variables yield the expression that characterises relationship of the base metal and shaping spacer plate metal penetration depths:

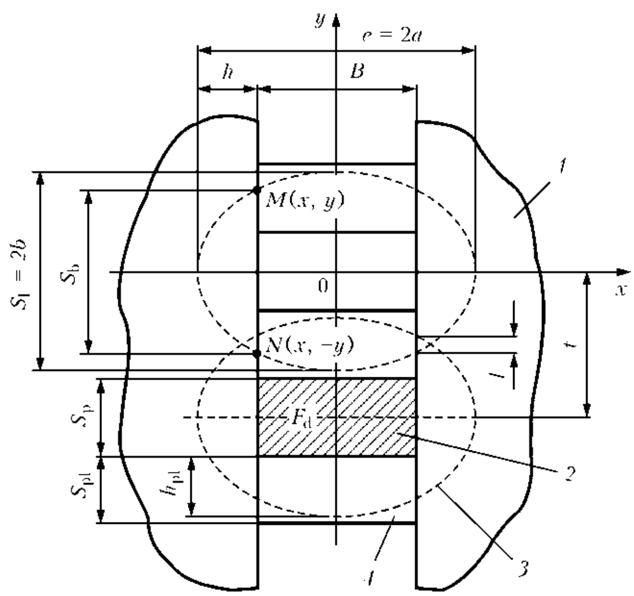

Figure 3. Scheme for calculation of groove and penetration shape in MESW: *1* — body of workpiece subject to repair; *2* — filled-in hole; *3* — penetration shape; *4* — bridge; *e* — width of a layer of multilayer weld; S_{pl} — thickness of shaping spacer plate; S_l — thickness of a layer of multilayer weld (see the text for the rest of the designations)

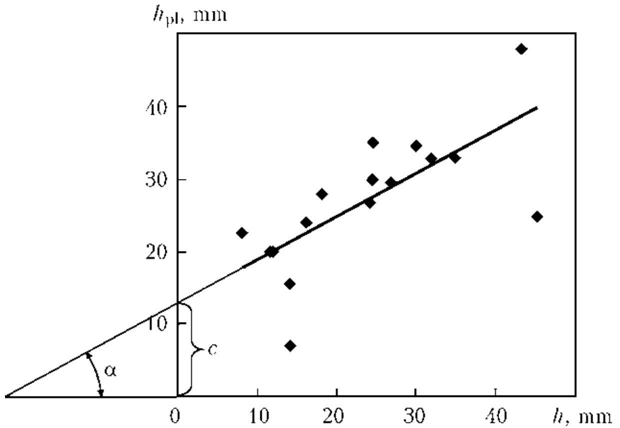

Figure 4. Ratio of base metal h to shaping spacer plate metal h_{pl} penetration depth in MESW with consumable nozzle

$$h_{pl} = 0.577h + 13. \quad (4)$$

By substantiating expression (4) to (2), we obtain the minimal required width of penetration of the base metal edges in the filled-in hole.

Pitch t of the filled-in holes (see Figure 3) should provide the guaranteed fusion of layers of the multilayer weld (Figure 5). For this, theoretically the width of the region of repeated penetration of the base metal edges, l (see Figure 3) should have a positive value (above zero). For practical calculations, allowing for permissible variations of the process parameters that occur during welding, this value should be not less than 5–8 mm.

The required value of pitch t was determined from the scheme of the groove with the expected penetration shape (Figure 6), wherefrom it follows that the unknown value can be expressed through the assumed width of penetration of the base metal edges, S_b:

$$t = S_p + S_{pl} = S_b.$$

The $t < S_b$ inequality should be met for the guaranteed fusion of layers of the multilayer weld.

To allow for the above required value of l, the t value can be expressed as follows:

$$t = kS_b, \quad (5)$$

where $k = 0.85–0.95$.

Substantiation of expression (2) to (5) yields

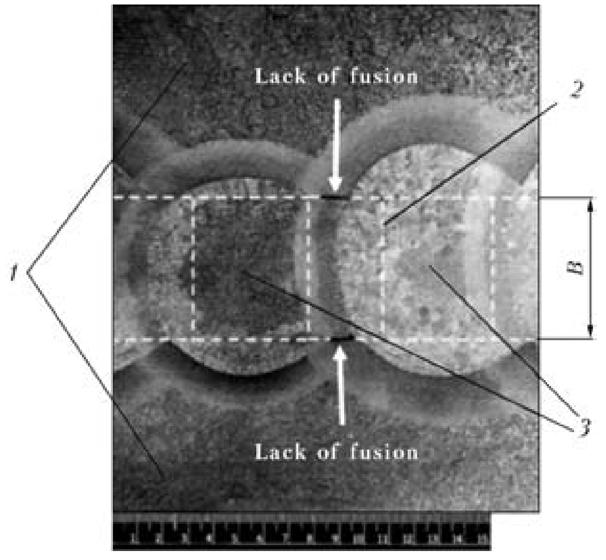

Figure 5. Transverse macrosection of a fragment of multilayer weld with defects: *1* — specimen pieces welded; *2* — shaping spacer plate; *3* — weld layers

$$t = 2k\sqrt{\left[1 - \frac{B^2}{B^2 + 4h(B + h)}\right]\left(\frac{S_p}{2} + 0.577h + 13\right)^2}. \quad (6)$$

This expression allows determining the required pitch of the filled-in holes to select the groove size and shape for MESW.

The calculated values were experimentally checked by making instrumental measurements of the above parameters in the scanned photos of transverse macrosections (Figure 7). The measurements were made by using software KOMPAS-3D V8.

Results of the calculations and measurements of geometric parameters of the penetration zone are summarised in the Table.

Comparative evaluation of the calculated and actual parameters of the shape and depth of penetration of the weld edges showed the following:

• the calculated shapes of penetration satisfactorily coincide with the actual shapes of penetration of the base metal and shaping spacer plates. Deviation of the actual fusion line from the calculated one is observed only in the closing (at the joint end) layers of the multilayer electroslag weld, this being caused by the end effect [13];

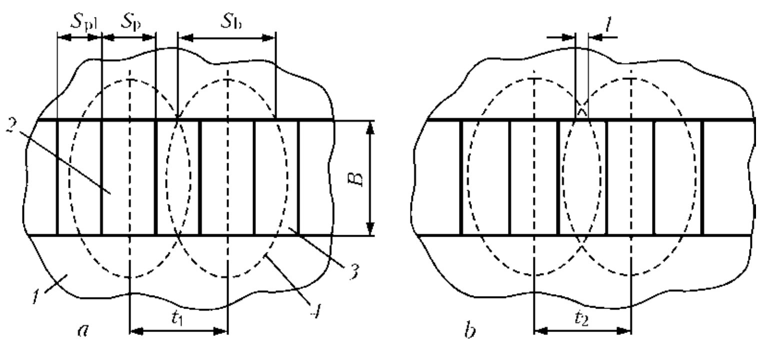

Figure 6. Scheme of groove and expected penetration shape in MESW with consumable nozzle: *a* — $l = 0$; *b* — $l > 0$; *1* — body of workpiece subject to repair; *2* — filled-in hole; *3* — shaping spacer plate; *4* — isotherm of melting; t_1 and t_2 — distances between axes of filled-in holes (pitch)

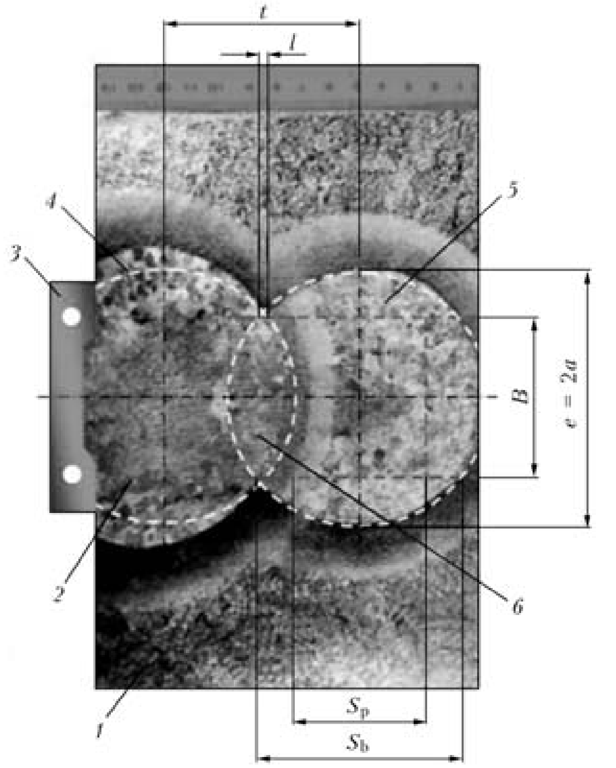

Figure 7. Transverse macrosection of a fragment of multilayer electroslag weld: *1* — workpieces welded; *2* — shape of groove for MESW; *3* — water-cooled shaping device; *4* — calculated shape of fusion line (zone); *5* — weld layer; *6* — shaping spacer plate

• the actual values of parameters of the penetration zone differ from the calculated ones by not more than 10 %, which is acceptable for engineering calculations. The actual value of penetration depth h, local width of penetration of the base metal edge, S_b, and width of the region of repeated penetration of the base metal edge, l, are a bit higher than the calculated values of these parameters, which provides the guaranteed fusion of layers of the multilayer weld for the selected groove shape.

Therefore, the procedure proposed allows calculation of the groove shapes at which the guaranteed fusion of layers of the multilayer electroslag welds is ensured.

Calculated and experimental values of groove shape and penetration depth in MESW with consumable nozzle

B, mm	S_p, mm	h, mm	Number of weld layer	Calculated values, mm				
				$2a$	$2b$	S_b	t	l
60	50	15	3	90	93.40	69.9	66.40	3.50
			4					
70	45	30	5	130	105.62	89.0	75.65	13.35
			3					

Cont.

Actual values, mm					
h	e $(2a)$	S_l $(2b)$	S_b	t	l
$\frac{15.0-17.5}{16.25}$	90	98	$\frac{76.0-77.0}{76.5}$	74	$\frac{3.4-4.2}{3.8}$
24	108	–	–		
$\frac{28-32}{30}$	127	112	91.0	73	$\frac{14.0-15.5}{14.75}$
$\frac{28.5-37.5}{33}$	140	109	$\frac{91.0-98.0}{94.5}$		

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