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EXPERIMENTAL STUDIES OF BIFILAR ELECTROSLAG WELDING WITH AN EQUALIZING WIRE

Yu.M. Lankin, O.P. Bondarenko, V.G. Tyukalov, V.G. Soloviov, I.Yu. Romanova

E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine

ABSTRACT

At bifilar electroslag welding, compared to the traditional two-electrode circuit, the path of current flowing in the slag pool is significantly different, and, consequently, the position of heat evolution zones and electromechanical forces acting on the molten slag and metal, changes drastically. Experiments showed that at bifilar electroslag welding penetration of the edges of welded item metal is considerably smaller, and reduction of the welding gap becomes possible that allows raising the welding speed at the same power, and power factor cos φ increases essentially from 0.67 to 0.9. Connection of equalizing wire between the midpoint of output winding of power transformer and the item being welded ensures stability of the electroslag welding process by the bifilar circuit of power source connection.

KEYWORDS: electroslag welding, bifilar power circuit, edge penetration, process stability, power factor

INTRODUCTION

Electroslag welding (ESW) is performed with application of one, two, three and more electrode wires. In two-electrode machines the electrode wires are connected to the power source in parallel by electrode–welded item circuit. Such a connection is believed to be traditional. At electroslag remelting (ESR) with two electrodes the bifilar circuit of electrode connection to the power source became widely accepted [1–5]. Bifilar ESR has certain advantages over ESR with electrodes connected in parallel. Bifilar ESW by wire electrodes is not applied now. However, there is ground to believe that it has even more advantages over bifilar ESR. As the cross-sectional area of consumable electrodes in ESW and ESR differs considerably, the thermophysical processes, causing their melting, also differ essentially. Compared to the traditional circuit with two electrodes, at bifilar ESW the path of current flowing in the slag pool changes significantly, and, consequently, the position of heat evolution zones, electromechanical forces acting on molten slag and metal, also changes dramatically. Therefore, a physical experiment is required to study the process of bifilar ESW. We are not aware of any publications on conducting ESW with the bifilar circuit of unit connection to the power source, except for the experiment on the mathematical model [6, 7].

The objective of experimental studies is comparison of the results of ESW by bifilar scheme of connection to the power source and traditional two-electrode connection circuit. The anticipated results of the work can be useful for different mechanical engineering industries, as they will create real conditions for increasing ESW productivity and operational efficiency of welded joints of carbon, low- and medium-alloyed steels of large thickness (40–250 mm).

MATERIALS, METHODS AND RESULTS OF EXPERIMENTS

The work was performed under the conditions of PWI laboratory*. In order to check the equipment performance and welding procedures, experimental studies of bifilar ESW with an equalizing wire were performed in comparison with the traditional ESW circuit with two wire electrodes. Experiments were performed in a unit, fitted with A-535 machine with liquid metal level regulator, level sensor and digital meter of electrode wire feed speed, as well as power transformer TShS-1000/3 with thyristor voltage stabilizer at the high-voltage side. The unit circuit enabled operation by the traditional or bifilar power circuit with zero wire.

Experiments were conducted using samples from low-carbon structural steel 70 mm thick, sample dimensions were 420×200×70 mm. Welding wire of 3 mm diameter and flux of AN-8 grade were used as welding consumable. In all the experiments number of electrodes was 2, interelectrode distance was $d =$ $= 55$ mm, dry electrode extension was 90 mm. Welding by the traditional and bifilar circuit was conducted at practically same power P and electrode feed rate V_f, same gaps b and slag pool depths h_{sl}. One welding operation was purposefully performed in a narrow gap ($b = 20$ mm) to determine the possibilities of the bifi-

*O.A. Moskalenko took part in the work performance.

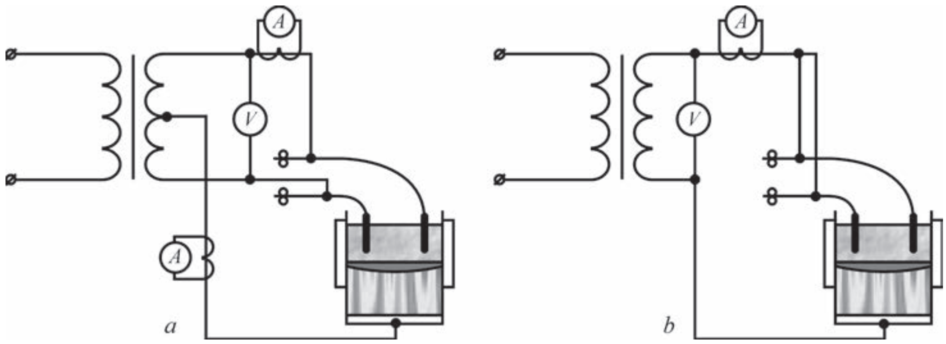

Figure 1. Experimental circuits of bifilar ESW with an equalizing wire (*a*) and traditional ESW (*b*)

Table 1. Main parameters of welding modes

Parameter description	Sample number			
	1	2	3	4
Power circuit	Bifilar	Traditional	Bifilar	Traditional
Welding gap *b*, mm	32	32	20	32
Interelectrode distance *d*, mm	55	55	55	55
Welding voltage *U*, V	76	38	76	55
Wire feed rate V_f, m/h	230	240	235	230
Welding speed V_w, m/h	1.45	1.51	2.37	1.45
Electrode current *I*, A	500	960	520	1120
Equalizing current h_{eq}, A	0	-	60	-
Slag pool depth h_{sh}, mm	50	55	40	50
Power applied to the slag pool *P*, kW	38	36.5	39.5	61.6
Power factor cos φ, rel. un.	0.9	0.7	0.89	0.68
Edge penetration depth, mm	8	13	7	22

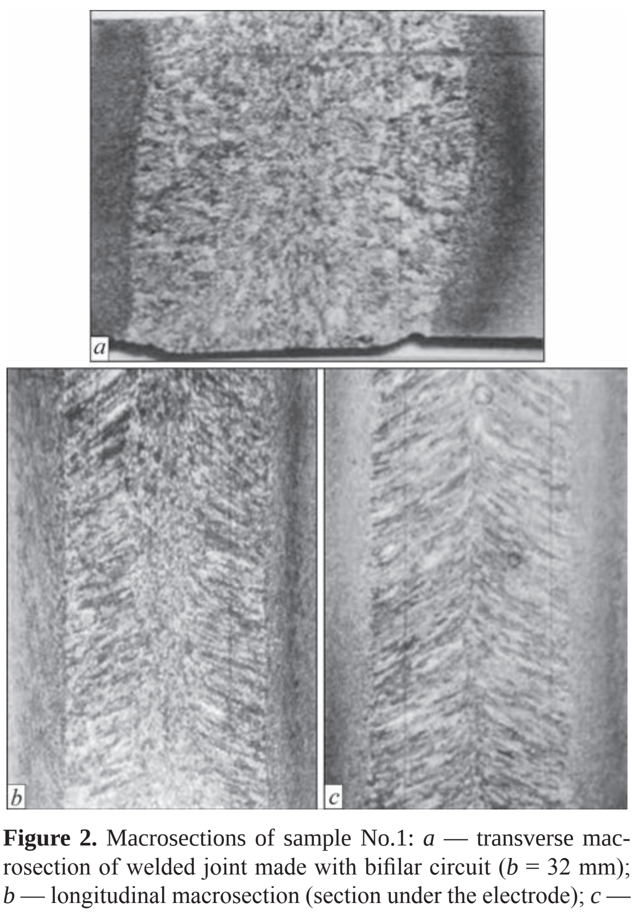

Figure 2. Macrosections of sample No.1: *a* — transverse macrosection of welded joint made with bifilar circuit (*b* = 32 mm); *b* — longitudinal macrosection (section under the electrode); *c* — longitudinal macrosection (section between the electrodes)

lar power circuit. Another ESW operation by the traditional scheme was performed at a higher (1.7 times) welding power at practically the same electrode feed rate. All the electric mode parameters were recorded in keeping with Figure 1.

The main parameters of the welding modes are given in the Table 1, and welded joint macrosections are shown in Figures 2–5.

DISCUSSION

The electroslag process was stable in welding all the samples (Nos 1–4). It is known that the process of single-electrode ESW with power supply from a source with rigid external characteristic is stable, as it has the self-regulation property, similar to the consumable electrode arc welding process. In bifilar ESW without the equalizing wire self-regulation is absent and such a process is unstable at the action of disturbances on it, which are inevitable under the real conditions. Application of equalizing wire, as shown in Figure 1, *a*, ensured self-regulation, and, hence, also the stability of bifilar ESW without the automatic regulation systems with negative feedbacks.

When using the bifilar power circuit of ESW with an equalizing wire, the process of "cold" start is essentially simplified and shortened, compared to the traditional ESW with two wire electrodes. At this stage,

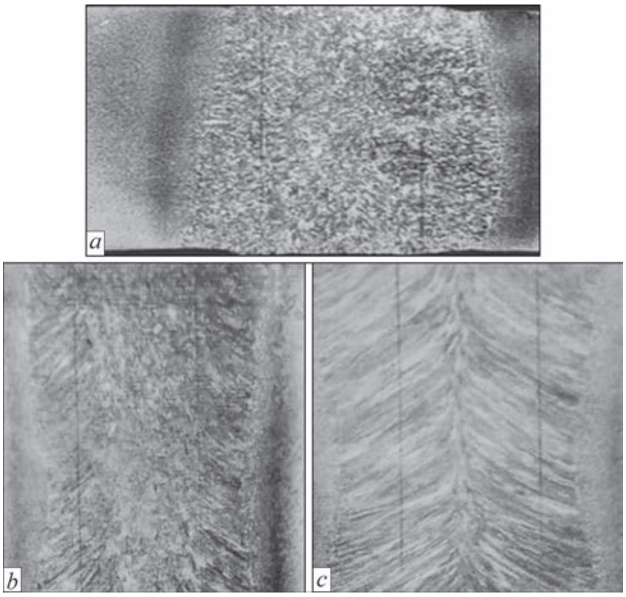

Figure 3. Macrosections of sample No.2: *a* —transverse macrosection of welded joint made by ESW with the traditional circuit (*b* = 32 mm); *b* — longitudinal macrosection (section under the electrode); *c* — longitudinal macrosection (section between the electrodes)

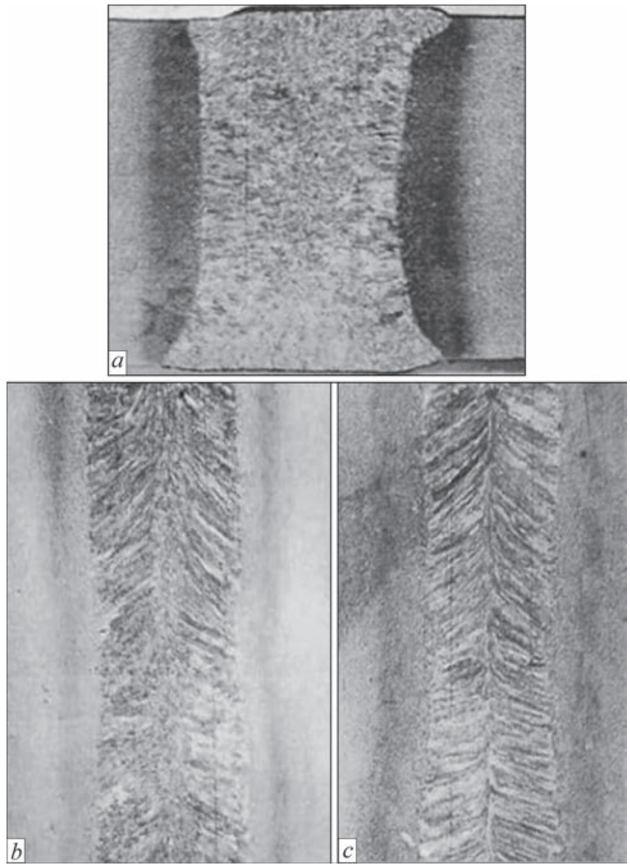

Figure 4. Macrosections of sample No.3: *a* — transverse macrosection of welded joint made by ESW by bifilar circuit (*b* = = 20 mm); *b* — longitudinal macrosection (section under the electrode); *c* — longitudinal macrosection (section between the electrodes)

each electrode is powered practically individually from its half of the transformer secondary winding, and slag melting is performed by two electric arcs simultaneously, burning between the electrode edges and inlet pocket. At this stage, all the current runs through the equalizing wire. After slag melting, it becomes electrically conducting, and the electric arc process turns into the electroslag one. Gradually, an ever greater part of the total current starts flowing between the electrodes, and current in the equalizing wire decreases to zero. Only at very small welding gaps current, which is due to currents between the electrodes and edges of the item being welded, can flow continuously through the equalizing wire. This current is small, for instance, in welding sample No.3 (welding gap of 20 mm), it was equal to 12 % of the total welding current.

One of the main advantages of ESW bifilar power circuit is smaller depth of the edges of item being welded. As one can see from the Table 1, the penetration depth of the edges of item being welded at ESW by the bifilar circuit (sample No.1) is by 40 % smaller than that of penetration of the edges at ESW by the traditional circuit (sample No.2) at other welding conditions being equal.

Another important advantage of bifilar ESW is the possibility of welding into a narrow gap of 20 mm (sample No.3) that allowed increasing the welding speed by 63 %, compared to sample No.1, at the same power.

A thinner macrostructure of welds made by the bifilar power circuit is noted. The presence of two different macrostructures in the sections under the electrodes and between the electrodes was established both with the traditional and the bifilar power circuit:

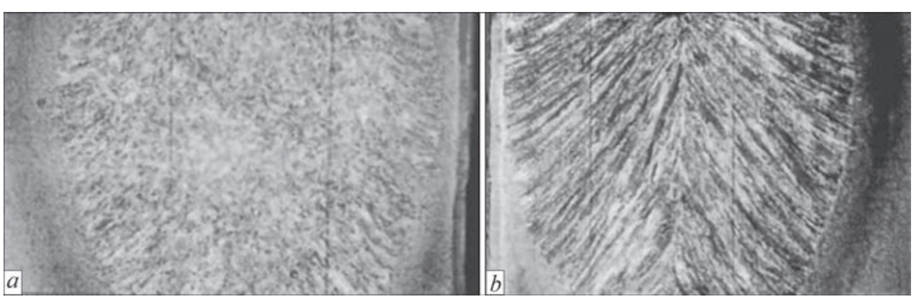

Figure 5. Longitudinal macrosections of welded joint on sample No.4 made by ESW by the traditional circuit, at higher power (1.7 times higher): *a* — section under the electrode; *b* — section between the electrodes

● dendritic and disoriented cellular-dendritic macrostructure under the electrodes;

● coarse dentritic macrostructure between the electrodes (for all the welds in different gaps).

However, in sample No.4 the coarse dendritic macrostructure is more expressed, compared to sample No.2. It is envisaged that at traditional ESW direct flowing of current (electrode-bottom plate) may lead to slag overheating, and, accordingly, metal pool deepening that does not allow increasing the linear welding speed ("hot" cracks can form in the weld, so-called critical ESW speed).

At bifilar power circuit of ESW the respective relative arrangement of power cables, connecting the power source to the welding machine, enables a significant reduction of inductance of the power source secondary circuit. As a result, for instance, for our welding unit power factor cos φ increased from 0.7 for the traditional circuit to 0.9 for ESW bifilar power circuit. Such an increase of power factor greatly decreases the load on the external electrical network and reduces power losses.

CONCLUSIONS

ESW by the bifilar circuit allows redistributing the components of thermal balance in the slag pool. Here, it is possible to essentially increase the welding speed without any negative consequences for weld metal quality.

Equalizing wire ensures stability of ESW process with a bifilar power circuit.

The depth of penetration of edges of the item being welded is much smaller with ESW bifilar circuit, than with the traditional two-electrode ESW circuit.

It became possible to use 20 mm gaps between the edges that greatly improved the energy values of ESW process at a considerable increase of linear welding speed.

Finer macrostructure of the welds, made by the bifilar power circuit, is noted.

At transition from ESW traditional power circuit to the bifilar one with an equalizing wire cos φ of the unit increased abruptly (from 0.7 up to 0.9) that may ensure an improvement of operating conditions of the unit external network.

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ORCID

Yu.M. Lankin: 0000-0001-6306-8086,
V.G. Tyukalov: 0000-0003-3491-193X,
V.G. Soloviov: 0000-0002-1454-7520,
I.Yu. Romanova: 0000-0001-7154-1830

CONFLICT OF INTEREST

The Authors declare no conflict of interest

CORRESPONDING AUTHOR

Yu.M. Lankin
E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine
E-mail: lankin.y.n@gmail.com

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