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ELECTROSLAG SURFACING WITH LARGE-SECTION ELECTRODE AT DIRECT CURRENT IN CURRENT-SUPPLYING MOULD

Yu.M. KUSKOV, V.G. SOLOVIOV, P.P. OSECHKOV and **V.V. OSIN**
E.O. Paton Electric Welding Institute of the NAS of Ukraine
11 Kazimir Malevich Str., 03150, Kyiv, Ukraine. E-mail: office@paton.kiev.ua

The influence of different circuits of electrode connection to one or two DC power sources on base metal penetration at electroslag surfacing of end faces was studied. It is established that the circuits of electrode connection both to one and two DC power sources can be used to obtain minimum and uniform penetration. Shortening of the distance from the processed surface (billet end face) to the current-conducting section of current-supplying mould leads to an increase of surfacing efficiency and reduction of specific power consumption. 12 Ref., 1 Table, 3 Figures.

Keywords: *electroslag surfacing of end faces, large-section electrode, current-supplying mould, DC power sources, processed surface, base metal penetration*

Alternating current of commercial frequency is traditionally used for powering electroslag furnaces (processes of electroslag remelting (ESR), electroslag casting (ESC)), welding and surfacing units (processes of electroslag welding (ESW) and electroslag surfacing (ESS)) [1, 2]. For furnaces this choice is due to simplicity of electrical equipment and high quality of the produced metal. For welding-surfacing units the determinant factor also is the lower cost and simplicity of electrical equipment. Here, for instance, the stability of ESW process at alternating current is not worse than that at direct current, and in the case of operation at direct current at its large values, electrolysis phenomena proceeding in the slag pool, may disturb process stability.

However, direct current was quite extensively used abroad at the initial stage of ESR development. And at present both combined current with superposition of direct current on alternating current, and purely direct current of different polarity can still be used for different reasons (production, metallurgical and economic) [3–7]. In [6] some features of electroslag process at direct current are generalized. It was necessary to check the advantages of direct current (depending on polarity), compared to alternating current, at ESS in a current-supplying mould (CSM).

This work is a continuation of investigations of ESS of end faces by large-section electrodes (40–130 mm diameter), using CSM of 180 mm diameter [8, 9]. Its objective is evaluation of the prospects for direct current application at ESS, when using one or two sources and different circuits of connection of the electrode, item and current-conducting section of the mould. Metallurgy of electroslag process at direct current was not considered in this paper.

Procedure of experiment performance differed from that accepted in [9] by that the experiments were performed only with 90 mm electrode at liquid start, and power sources were VDU-1202 and VDM-5000. Measurement, as well as recording of currents and voltages, was conducted using equipment and software indicated in [9]. Figure 1 shows the structural diagram of electrical connections during performance of experiments for one-loop (*a*, *b*) and two-loop (*c*) ESS.

First of all, before the start of experiment performance, it was necessary to more precisely determine the possibility of CSM operation at reverse polarity. Already at the beginning of investigation of electroslag process in a standard mould, it was established [10] that at application of nonconsumable water-cooled copper electrode and fluxes of different chemical composition a stable process was observed only in the case, when the electrode was the cathode (straight polarity). The process at reverse polarity could only be realized using slags, not containing SiO_2, in particular, with chemically pure CaF_2. However, in this case, an intensive destruction of the electrode surface was observed. At application of a carbon electrode, the process stability did not differ from that found at melting of consumable metal electrodes (steel, copper, tungsten, molybdenum, etc.).

It should be noted that one of the developers of CSM design also states that the current-supplying mould can be operated only at applying straight polarity direct current to it. At reverse polarity the electroslag process is gradually phasing out [11]. As one

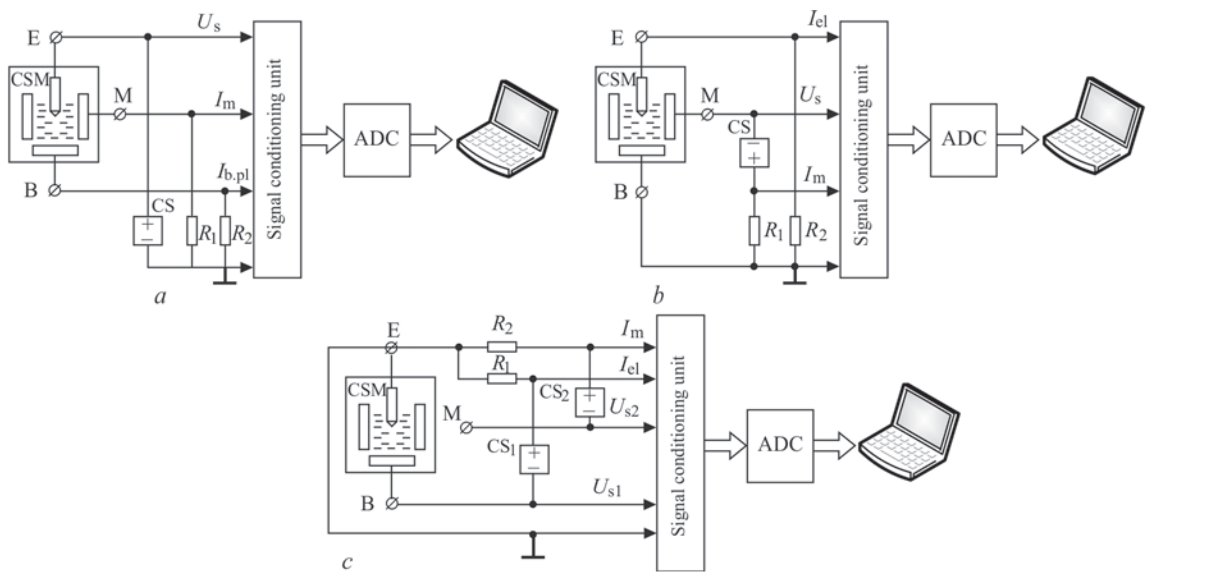

Figure 1. Structural diagram of electrical connections for performance of experimental surfacing for one-loop (*a*, *b*) and two-loop (*c*) ESS: E, M, B are the terminals of connection of the electrode, mould current-conducting section and bottom plate with the item, respectively; CS (CS1 and CS2) is the direct current source; *R1* and *R2* are the measuring current shunts; U_s (U_{s1} and U_{s2}), I_m, $I_{b.pl}$ and I_{el} are the signals proportional to current source voltage, mould, bottom plate and electrode current, respectively; ADC is the analog-digital converter

can see, there is a certain contradiction between the data in [10, 11]. In the first case, the electroslag process with carbon electrode is stable at direct current of any polarity, similar to consumable electrode melting. Now, in the case of application of CSM, the copper current-conducting section of which is protected by graphite (carbon) lining, through which current flows into the slag pool, the process at reverse polarity is not only not stabilized, but even stops.

In view of the fact that during setting the slag pool in the mould, the solid start is also used in a number of cases, alongside the liquid one, the electroslag process was studied under the conditions, when the water-cooled electrode (with a graphite attachment at its working end face) and CSM current-conducting section (having a graphite protective lining) were the anode and cathode relative to the bottom plate with the billet, respectively. VDM-5000 power source and ANF-29 flux not applied earlier in the above mentioned works, were used in the experiments.

The experiment with water-cooled electrode and graphite attachment was conducted by setting a slag pool in the CSM forming section, without applying voltage to its current-conducting section, i.e. CSM in this experiment was a standard mould. The slag pool was set only at the attachment surface in the form of a ring approximately 30 mm wide and even at increase of thermal power applied to the pool, this zone did not essentially change its dimensions. In addition, microarcs, similar to those described in [10], were observed on the upper interphase of slag — attachment surface around the entire perimeter. The process had to be stopped. Examination of the attachment working part showed the following. A band about 5 mm wide and 3–5 mm deep formed on its end face. Here, that entire «trench» is covered by small pits, which, obviously, are the sites of microarc appearance. Now in the region, where the microarcs were observed on the slag surface, no visible changes were found on the attachment surface. Schematic of attachment wear and its appearance after testing are shown in Figure 2.

Testing CSM serviceability at reverse polarity was performed by pouring molten slag overheated in a separate tank, inside the same mould, but with voltage application to its current-conducting section. Already a few seconds after pouring, the slag pool started cooling down; bright glow and some movement of slag were noted just in its local zones. Then, pool cooling occurred over its entire surface with current lowering to zero.

Thus, neither the water-cooled graphite electrodes, nor CSM current-conducting sections, having a pro-

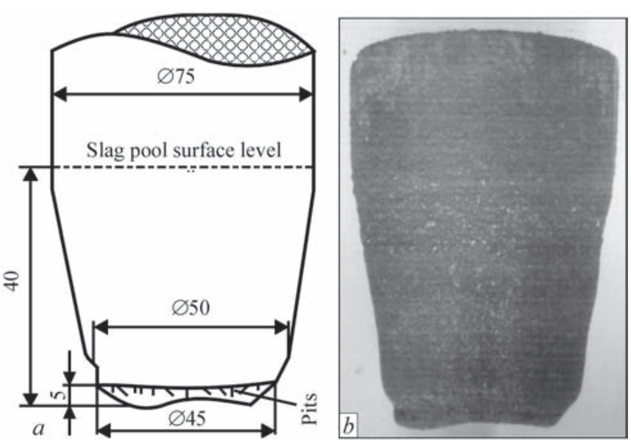

Figure 2. Schematic of attachment wear (*a*) and its appearance after testing (*b*)

Parameters of electroslag surfacing of end faces in CSM at direct current

Experiment number	Electrode diameter, mm	Connection circuit	Current, kA		Voltage, V			N_t, kV·A	N_m/N_t, %	V_{el}, mm/min	G, kg/h	h, mm	Q, kW·h/ kg	Surfacing quality		
			C	E	C	E	B							H_{av}, mm	Δ_{av}, mm	PSFQ
45M	90	OLC1	2.3	2.6	0	43	0	110	88	34	83	44	1.3	1	0.8	Satisfactory
46M	90	OLC2	2.94	1.09	0	36	36	106	100	14	21	44	5	3	2	Good
47M	90	TLEl	0.74	1.87	6	62	0	111	40	42	69	44	1.6	1	0.8	Good

Note. OLC1 and OLC2 are the one-loop circuits of CSM connection, the first with the same potentials at the item and CSM current-conducting section, the second with the same potentials at the item and electrode, respectively; TLEl is the two-loop circuit of CSM connection with a common point of connection on the electrode; N_t is the total power consumed by CSM; N_m/N_t is the ratio of power at the mould and the total power; V_{el} is the linear speed of electrode movement; G is the surfacing efficiency; h is the distance from the processed surface to the forming section top; Q is the specific power consumption; H_{av} is the average penetration depth; Δ_{av} is the average nonuniformity of penetration; PSFQ is the processed surface formation quality (expert evaluation).

tective graphite lining, allow conducting a stable electroslag process at reverse polarity.

Proceeding from the obtained results, surfacing in CSM should be performed at straight polarity. However, some explanation of the terminology is required. In welding science it is customary to evaluate polarity in a relative form [12]. This implies existence of the following relationships: if voltage is applied to the item from power source (+) terminal, and to the electrode — from (–) terminal, then polarity is considered to be straight. In case of reverse connection, reverse polarity is in place. In [6] the features of electroslag process at different polarity are considered exactly proceeding from such a connection to the power source.

Now, if during the electroslag process the slag pool is in contact not with one, but with two electrodes (consumable electrode and CSM current-conducting section), there arises an uncertainty at assessment of the type of mould connection relative to the consumable electrode. In order to eliminate this uncertainty, at further consideration of various electric circuits of connection of the source (sources), we will use just (+) or (–) symbol designations, without specifying the surfacing process polarity.

The Table gives the results of experiments on investigation of the influence of electric parameters of the process of ESS at direct current in CSM (at application of different schematics of its connection) on base metal penetration.

Three experiments with one-loop OLC1 (Figure 1, *a*), and OLC2 (Figure 1, *b*) circuits and with two-loop TLCEl (Figure 1, *c*) circuit of current source connection were performed. Here, preliminary experiments on ESS with OLC1 circuit with electrode connection to terminal (–), as well as OLC2 circuit with CSM current-conducting section connection to (+) terminal, showed negative results, the process was sluggish with its phasing out that is associated with the presence of a «valve effect» at ESS. Therefore, experiments 45M and 47M were performed with consumable electrode connection to terminal (+).

Figure 3. Macrosection of bimetal billet from experiment 45M

It was established that samples produced in experiments 45M and 47M have, practically, the same indices of surfacing quality. Here, in the sample from experiment 45M the values of efficiency and specific power consumption are somewhat better. More over, TLCEl circuit (Figure 1, *c*) is more complex to implement, because of availability of two power sources. It follows that electroslag surfacing of end faces at direct current with one-loop circuit of connection to the current source, is preferable, compared to two-loop circuit. Figure 3 shows the macrosection of a bimetal sample from experiment 45M.

From the three conducted experiments, experiment 46M showed the worst results, both as to process efficiency, and as to specific power consumption. Experiment with OLC2 circuit (compared to OLC1) leads to 4 times reduction of G, 3.8 times increase of Q, increase of H_{av} from 1 to 3 mm and of Δ_{av} from 0.8 up to 2.0 mm. Such results are attributable to the fact that the highest current equal to a sum of currents at the electrode and the item, flows through CSM. Due to that, the fraction of power consumed for electrode melting and metal pool heating, decreased, while efficiency dropped and power consumption increased, respectively. The results of experiment 46M with the circuit with the same potentials at the billet and the electrode, lead to the conclusion that surfacing with such a connection circuit should not be used for high-quality ESS.

It is interesting to compare the results of experiments, conducted with application of an alternating current source [9] and direct current source with the same connection circuits and with the same electrode diameters, but with different arrangement of the processed surface, relative to the top of the forming section. Experiment 22M [9] was conducted with $h = 85$ mm, and 45M with $h = 44$ mm. Two times reduction of the distance between the processed surface and forming section top led to increase of ESS process efficiency 1.7 times, and reduced power consumption 1.8 times, value of average penetration depth of base metal from 7 to 1 mm and value of average non-uniformity of penetration from 3.0 to 0.8 mm.

Work [9] analyzed the prospects of studying ESS by the two-loop power circuit with a common point of connection of both the sources on the electrode, presumably having a higher efficiency that the circuit with a common point of connection on the item. In this work, experiment 47M was conducted with connection of two direct current sources, having a common point of connection on the electrode (Figure 1, *c*). The consumable electrode and CSM current-conducting section are connected to (+) terminals.

The potential at the electrode with respect to the item is +62 V (see Table), and on the mould current-conducting section it is +6 V, respectively. On the mould current-conducting section the potential relative to the electrode is equal to –56 V, i.e. the current practically does not flow through the mould current-conducting section to the item that, in our opinion, should lower the effectiveness of the process with this circuit of source connection. We performed experiment 25M [9] with connection of two alternating current sources, having a common connection point on the item. Electrode voltage was approximately 68 V, voltage of the mould current-conducting section was about 37 V. Comparison of the results of the considered experiments reveals the advantage of ESS process at direct current. So, experiment 47M, unlike 25M, shows an increase of process efficiency, reduction of specific power consumption and improvement of fusion quality. This is, supposedly, related to the fact that an increased near-anode potential drop is created at the electrode, which is the anode that promotes an increase of electrode melting rate. In addition, 1.13 kA current flows through the item (current on the electrode, minus current on the mould). This is equal to 60 % of total current flowing through the electrode that promotes good fusion of the base and deposited metals.

Conclusions

1. Possibility of performance of ESS of end faces at different electric circuits of electrodes connection from one or two DC power sources was established and influence of electric and process parameters on base metal penetration was studied.

2. It was established that the circuits of electrode connection both to one and two DC power sources can be applied, in order to achieve a minimum and uniform penetration. However, surfacing at DC current with two-loop circuit of connection of power sources, compared to one-loop circuit, is less preferable, because of the complexity of its realization (presence of two power sources).

3. Shortening of the distance from processed surface (billet end face) to CSM current-conducting section leads to an increase of surfacing efficiency and to reduction of specific power consumption.

4. Experiments showed that ESS at direct current with the circuit with the same item and electrode potentials does not allow achieving high-quality surfacing.

5. As was assumed in [9], ESS with a two-loop power circuit with a common point of connection of both the sources on the electrode has a higher efficiency and lower specific power consumption, than that with a common point of source connection on the item.

6. Obtained results can make up a data bank for construction of a system of automatic regulation of base metal penetration at ESS of end faces.

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