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ELECTROSLAG SURFACING OF END FACES WITH LARGE-SECTION ELECTRODE IN CURRENT-SUPPLYING MOULD

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

It is proposed to perform electroslag surfacing of end faces with application of current-supplying mould (CSM) and feeding large-section remelting electrode into its central part. Two variants of electric circuits of remelting electrode connection are proposed. In the first circuit the same potential is applied both to consumable and annular nonconsumable (CSM upper section) electrodes. In the second circuit, potentials of both the electrodes are different. The following technique of surfacing was proposed as a result of test surfacing performed with ANF-29 flux in CSM of 180 mm diameter with steel 40 electrodes of 40–130 mm diameter. After setting the slag pool in CSM, it is recommended to conduct the first stage (joining the base and deposited metal) with the first electric circuit. Electrode melting will be slower, but with optimum electric power applied to the slag pool through CSM, it is possible to achieve uniform penetration of base metal. Furtheron, at deposition of subsequent layers with higher efficiency and good quality of the deposited layer, one should proceed to the second electric circuit of remelting electrode connection. 8 Ref., 5 Figures.

Keywords: *ESS of end faces, large-section electrode, CSM, ESS electric circuits, base metal penetration, deposited metal formation, efficiency*

Quality of surfacing performed by any known method, particularly at joining metals with markedly differing properties, is largely determined by the ability to reach minimum and uniform penetration over the entire surface being joined. Otherwise, the problem of imparting special properties (wear resistance, thermal fatigue resistance, corrosion resistance, etc.) to the deposited metal is not completely solved. This is particularly important as regards relatively small thicknesses of the deposited metal. Depending on the method of electroslag surfacing (ESS), the proportion of base metal in the deposited metal is equal to 5–20 % [1]. Nonetheless, the main advantage of many ESS methods, alongside the high process efficiency, is the ability to deposit large metal masses.

In this case, preservation of preset special properties of the deposited metal across the deposited layer thickness does not cause any difficulties (particularly, in layers located far away from the fusion zone). Difficulties may arise in the bimetal fusion zone, because of a greater or smaller degree of mixing of the metals being joined and formation of intermediate structures with brittle components (martensite, carbide, nitride, and similar precipitates with different sizes and arrangement) in this zone, which markedly lower the joint mechanical strength, or promote formation of defects, most often cracks, already during surfacing. That is why this is exactly the problem which does not allow completely realizing all the advantages of the high-efficient process. A vivid example of such a situation is the so-called bulk ESS of teeth of mining shovel buckets [2]. This is good technology, which solves the major task of reconditioning expensive mining tools, but the surfaced (reconditioned) ladles are mostly used in operation for relatively easy to process rocks, when no increased impact loads are created.

It would seem that the simplest solution of this problem is performance of complex heat treatment of the bimetal product. This, however, is simply impossible to perform in most cases, because of absence of thermal furnaces with suitable dimensions and temperatures, and most importantly, the efficiency of the surfacing process becomes lower, and the rationality of its application is lost.

Thus, while the penetration depth is an important characteristic of any surfacing process (arc, plasma, etc.), it acquires special importance for ESS in the case of poor quality surfacing of large masses of often expensive metal. It should be noted that in this case removal of fusion zone defects also is a difficult-to-perform task.

The objective of the work is obtaining initial experimental data and selection of the direction of further studies to create a system of automatic regulation of quality at ESS of end faces with a large-section electrode in CSM.

At ESS in water-cooled devices-moulds wire or strip electrodes, or so-called large-section electrodes (bars, rods, etc. with up to 35000 mm^2 cross-sectional area) are usually used as electrodes. These technologies can be regarded as particular cases of the known and well-studied electroslag process — electroslag remelting (ESR). The difference consists only in that in the first case metal of a particular thickness is deposited on the billet surface, and in the second case

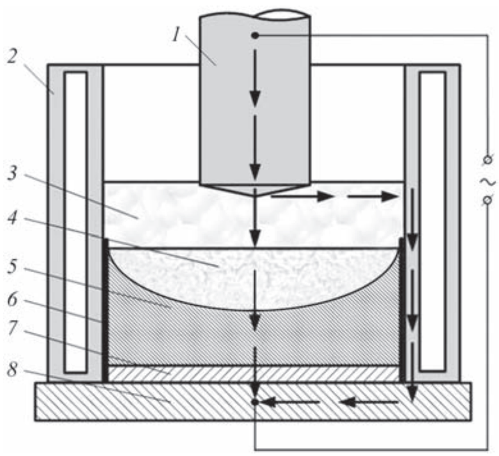

Figure 1. Metal pool shape at ESS (arrows show current distribution in the mould): *1* — electrode; *2* — mould; *3* — slag pool; *4* — metal pool; *5* — ingot; *6* — skull; *7* — seed; *8* — tray

the initial metal layer of ingot starts forming on the seed, which is a plate of 10–30 mm thickness. While for ESS, as we already noted, the penetration depth plays an essential role, at ESR the objective is just to achieve good fusion of seed and ingot metals, the more so since after remelting this lower (bottom) part of the ingot is removed (up to 15 % of ingot weight) [3]. For us it is important to assess formation of the metal pool (dimensions, depth) in a process similar to ESS, as it is exactly the heat transferred from the pool to the seed that determines heating and penetration of the latter.

It is seen from Figure 1 that the main thermal energy evolves under the electrode end face, imparting a specific cone-like shape to the metal pool. Accordingly, seed penetration is maximum along the ingot axis, with its decrease (or disappearance) along the ingot edges. From this analysis it follows that such an approach of metal joining cannot be applied to ensure high-quality surfacing.

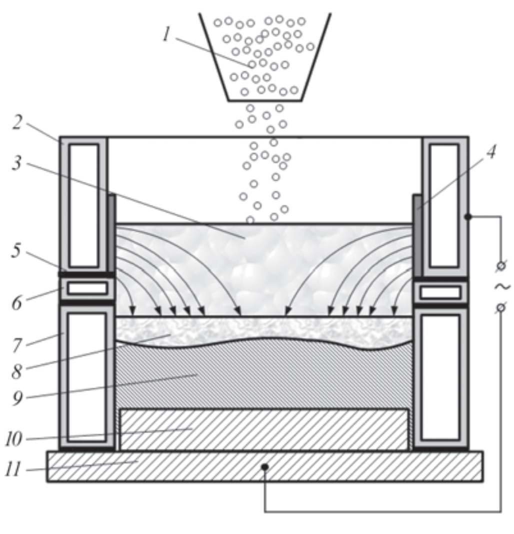

Figure 2. Shape of metal pool produced at ESS in CSM with discrete filler (arrows show current distribution in CSM): *1* — discrete filler; *2, 6, 7* — current-conducting, intermediate and forming sections of the mould, respectively; *3* — slag pool; *5* — insulating interlayer; *8* — metal pool; *9* — deposited metal; *10* — billet; *11* — tray

In order to eliminate this drawback, it can be promising to perform surfacing in CSM [4–7], which, essentially, is a sectioned nonconsumable electrode of annular type with voltage applied to its upper section. Such an electrode shape influences the nature of current distribution in the slag pool, respectively. Current from the wall of electrically supplying ring is partially flowing in the horizontal direction, but, mainly, it flows vertically to the processed surface of the billet. Here, its greater part flows directly in the near-wall area of the mould. This is confirmed also by the results of work [8] on simulation of the process of surfacing of end faces on conductive paper: approximately 50–90 % of current (depending on the distance from the mould wall) flows exactly in this area.

Figure 2 shows the shape of the metal pool obtained at surfacing in CSM with discrete filler, i.e. in the absence of a heat center in the middle of the mould, which is created by the electrode, as is usually the case at regular ESR.

It can be assumed that if we add the consumable surfacing electrode to CSM and distribute electric power between the annular nonconsumable electrode and consumable electrode in an optimum way, a minimum and uniform penetration of the base metal can be ensured.

We have conducted experiments on studying the applicability of one of the two electric circuits of consumable electrode connection in surfacing (Figure 3). According to the first circuit (Figure 3, *a*), the same potential is applied to electrodes of different type, and with the second one, the consumable electrode has a different potential.

Alongside achievement of minimum and uniform penetration of base metal, the quality of formation of outer surface of the deposited layer and deposition rate were taken into account as the criterion of optimality of the technology.

Experiments on surfacing were performed with a solid start in a stationary CSM of 180 mm diameter with electrodes of 40–130 mm diameter from steel 40. ANF-29 flux and alternating current were used.

Longitudinal sections were mechanically cut out of the surfaced billets, on which the fusion zone was studied after grinding and chemical etching. Appearance of surfaced billets (side surface and upper plane of the layer) was assessed visually.

Experiments on surfacing with the first (Figure 3, *a*) electric circuit (same potentials on electrode and CSM) showed the following. Melting of 90 mm electrode proceeds very slowly (compared to ESS process) at its immersion into the slag pool from 15 to 70 mm. Electrode melts only over its end face (side surface is not melted). No base metal penetration is observed. Deposited metal side surface has corrugations. In the case of application of larger diameter electrode (130 mm), the surfacing process proper and

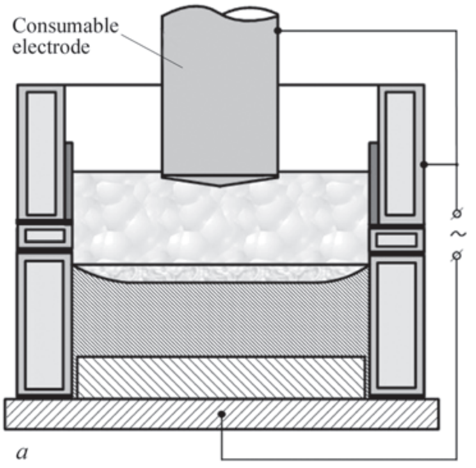

Figure 3. Electric circuits of remelting electrode connection at the same (*a*) and different from CSM (*b*) potential

its results are similar to those of surfacing with application of 90 mm electrode.

At surfacing with 40 mm electrode both accelerated melting of the electrode (at total applied power N = = 99 kV·A), and its delayed melting (N = 87 kV·A) are observed.

Apparently, stability of ESS process, speed of slag pool rotation, affecting the electrode melting and, eventually, process efficiency and surfacing quality, are largely determined by electric power N_{CSM}, applied to the slag pool through the CSM. Figure 4 shows the longitudinal macrosection of a bimetal billet, produced by surfacing with 40 mm electrode with N = 87 kV·A.

As follows from the results of surfacing with this electric circuit, at application of electrodes of different diameter no deep penetration of base metal is observed, either in the mould near-wall zone, not under the electrode. Therefore, such ESS circuit, in principle, allows creating a uniform thermal field, and, accordingly, similar penetration conditions over the entire surface of the billet being processed at appropriate optimum electric power applied through CSM. Another indirect confirmation of leveling of electric power across the mould cross-section and formation of a more flat metal pool in it is the increase of the speed of slag pool rotation at electrode removal from the slag due to redistribution of working current to the electrode and CSM in favour of the latter.

Surfacing with the second (Figure 3, *b*) electric circuit of remelting electrode connection showed the following results. First of all, this surfacing technology allows a significant increase of the efficiency of electrode melting process. So, at surfacing with 40 mm electrode the electrode melting rate rises up to 2–3 times, and at surfacing with 90 mm electrode — by approximately 2 times. Deposited metal formation and quality of the fusion zone substantially depend on surfacing mode. Figure 5 shows macrosections of a sample produced by surfacing with 90 mm electrode at different electric power of the process. At low power (N_{CSM} = 80–90 kV·A) «zero» fusion (by brazing type), formed under the impact of remelting electrode, is observed on 40 mm length in the central part of section, the other zones having deep penetration (≥20 mm) — Figure 5, *a*. This is accounted for by the fact that in this case the highest current was flowing from the annular nonconsumable electrode. Here, formation of the deposited layer side surface is unsatisfactory (presence of a large number of corrugations). At N_{CSM} = 130–135 kV·A (Figure 5, *b*) the central part of the section has small penetration (about 5 mm) on an approximately 50 mm length; in the other zones the fusion line has a lot of slag interlayers, without base metal penetration. Metal pool in the deposited metal has a relatively flat shape.

It follows from the above-said that surfacing by the technologies with different electric connection of the remelting electrode, can provide uniform and minimum penetration of base metal and allow achieving other criterial values at application of optimum electric power to the slag pool. Apparently, the following surfacing technique can be accepted for solving the defined problem. After setting the slag pool in the current-supplying mould (at solid or liquid start), the first circuit of remelting electrode connection should be used to conduct the first stage of surfacing (joining the base and deposited metals). Here, electrode melting will be delayed, but at optimum electric power applied to the slag pool through CSM, a uniform penetration of base metal can be achieved. Furtheron, i.e. at deposition of a thick layer, when it is necessary

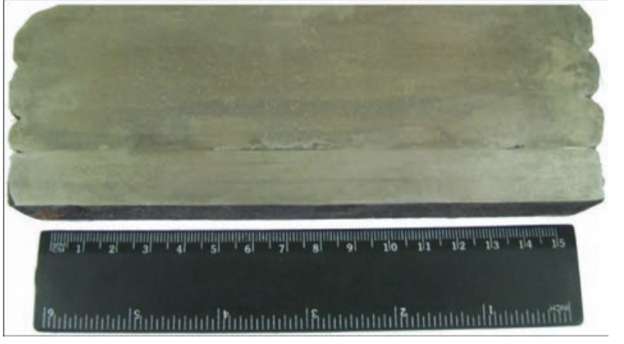

Figure 4. Longitudinal macrosection of bimetal billet, produced by surfacing with 40 mm electrode at N_{CSM} = 87 kV·A

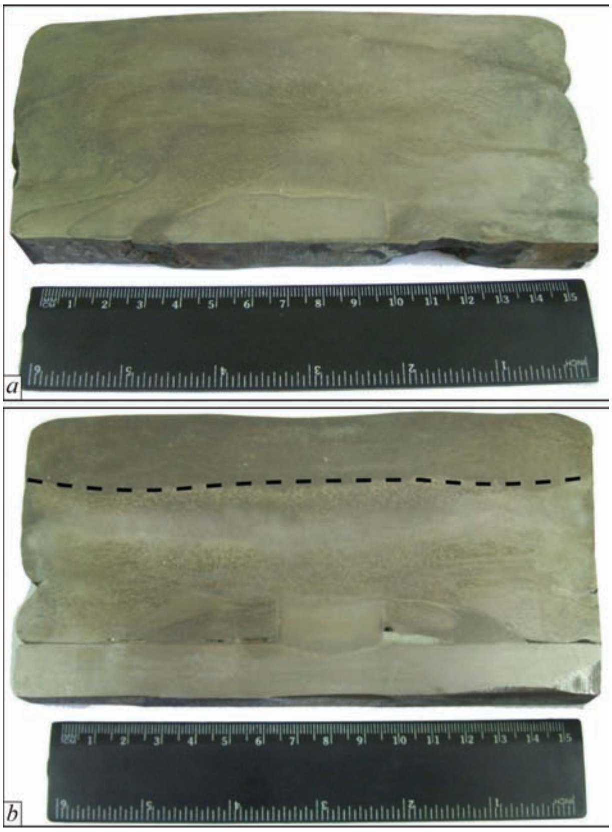

Figure 5. Longitudinal macrosection of a bimetal billet, produced by surfacing with 90 mm electrode at N_{CSM} = 80–90 (*a*) and 130 kV·A (*b*) (dashed line marks the shape of metal pool in the deposited metal)

to obtain higher process efficiency and high-quality surface of the deposited layer, the second circuit of electrode electrical connection should be applied.

On the whole, performed experiments showed that regulation of heat flows at ESS of end faces, both in the fusion zone, and at deposited layer formation is a complex task, solution of which depends on many parameters (both geometrical and electrical). Therefore, it is necessary to additionally perform a detailed, comprehensive investigation of this surfacing process. The following should be considered: application of other connection circuits, other number of power sources and kinds of applied current, application of not just remelting electrodes, but also nonsupplying consumable billets of different diameter, optimization of processed surface position relative to CSM current-supplying section.

Performance of such investigations will allow not only finding an optimum solution of the defined problem, but also creating prerequisites for automatic regulation of the process of ESS of end faces and obtaining the specified quality results even at deviation of the values of certain parameters from the initially assigned ones.

Conclusions

1. Unlike other surfacing processes, quality of electroslag surfacing with deposition of large masses of metal essentially depends on the fusion zone quality and to a smaller degree — on the quality of deposited metal proper.

2. The paper provides an analysis of the possibility of performance of ESS of end faces in the current-supplying mould with large-section electrode with application of two electric circuits — at the same and at different potential of the remelting electrode and CSM, in order not only to obtain minimum and uniform penetration of base metal, but also achieve high process efficiency with good formation of the deposited layer.

3. It is recommended to conduct the surfacing process at the first stage of metal joining by the technology, where the remelting electrode and CSM have the same potential. Furtheron, at deposition of subsequent layers, transition to the second electric circuit of remelting electrode connection should be made (electrode and CSM have different potentials). This will allow an essential increase of deposition rate with good formation of the deposited layer.

4. Proceeding from the performed studies, it was proposed to conduct a more comprehensive investigation of the process of ESS of end faces with large-section electrode. The following technological characteristics (both electrical and geometrical) were selected for consideration: electrode connection circuits, number of used power sources, kind of applied current, application of not just remelting electrodes, but also nonsupplying consumable billets, and position of the processed surface relative to CSM current-conducting section.

5. The final objective of the performed and planned investigations is formation of a data bank for developing a system of automatic regulation of the process of ESS of end faces and ensuring repeatability of surfacing quality results.

1. Kuskov, Yu.M., Skorokhodov, V.N., Ryabtsev, I.A. et al. (2001) *Electroslag surfacing*. Moscow, LCC Nauka i Tekhnologii [in Russian].
2. Ponomarenko, V.P.,Shvartser, A.Ya., Stroganova, G.V. (1985) Examination of fusion zone of high-chromium cast iron with high-manganese steel in electroslag surfacing. *Metallovedenie i Termich. Obrab. Metallov*, 11, 55–58 [in Russian].
3. Latash, Yu.V., Medovar, B.I. (1970) *Electroslag remelting*. Moscow, Metallurgiya [in Russian].
4. Frumin, I.I., Ksendzyk, G.V., Shirin, V.S. (1980) *Machine for electroslag remelting and surfacing*. USA Pat. 4185628 [in Russian].
5. Kuskov, Yu.M. Electroslag remelting in sectional current-supply mold. *Svarshchik*, **3**, 21–23 [in Russian].
6. Kuskov, Yu.M., Gordan, G.N., Bogajchuk, I.L. et al. (2015) Electroslag surfacing using discrete materials of different methods of manufacture. *The Paton Welding J*., **5–6**, 30–33.
7. Kuskov, Yu.M. (2003) A new approach to electroslag welding. *Welding J*., **4**, 42–45.
8. Tomilenko, S.V., Kuskov, Yu.M. (1999) Power specifics of electroslag process in current-carrying mold. *Avtomatich. Svarka*, **2**, 51–53[in Russian].

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