DOI: http://dx.doi.org/10.15407/tpwj2018.05.06

INFLUENCE OF ELECTRIC PARAMETERS OF SURFACING WITH DISCRETE FILLER IN CURRENT-SUPPLYING MOULD ON SPEED OF SLAG POOL ROTATION

Yu.M. KUSKOV
E.O. Paton Electric Welding Institute of the NAS of Ukraine
11 Kazimir Malevich Str., 03150, Kyiv, Ukraine. E-mail: office@paton.kiev.ua

Application of the most promising surfacing material — discrete filler — makes a significant difference in the processes of surfacing with current-supplying mould. Influence of electric parameters of surfacing on angular speed of slag pool rotation at application of three commercial flux grades was studied. It is found that ANF-29 flux allows producing a sufficiently large rotational effect both during the period of slag pool formation, and during surfacing. ANF-32 flux is less effective during the period of slag pool formation. AN-26 flux provides active rotation of the slag pool during surfacing, but this requires applying higher electric power to the pool. Angular speed of slag pool rotation is affected both by electric power applied to the slag pool, and surfacing current, but the latter has a determinant influence. 16 Ref., 1 Table, 2 Figures.

Keywords: *electroslag surfacing, current-supplying mould, fluxes, slag pool, angular speed of slag rotation, surfacing current, electric power, discrete filler*

One of the directions for improving the quality of electroslag metal due to acceleration of heat and mass transfer reactions, and the conditions of liquid metal solidification, is making external impact on the melting zone (electrode edge-slag-metal pool). This impact is most often provided by mechanical [1, 2], electromagnetic [3, 4] and ultrasonic [5] methods.

Despite the fact that most investigations confirm the positive influence of external impact on the deposited metal structure and properties, it, nonetheless, has not found a broad application, chiefly, because of complication of the electroslag process technology.

This drawback can be eliminated at application of sectioned current-supplying mould (CSM) developed at PWI, in electroslag technologies. One of its main functions in service is slag pool rotation in the horizontal plane [6]. This rotation is performed by electromagnetic method due to a special design of the current-conducting section. As a result of interaction of longitudinal magnetic field of the mould with the fields of lines of force of working current ponderomotive forces arise inside the slag pool, which mechanically create a rotational effect in the slag. Slag pool rotation as a result of the forces of friction between the slag and liquid metal is transferred to the metal pool.

Other problems can also be solved alongside the earlier mentioned objectives achieved at electroslag surfacing (ESS) and electroslag remelting (ESR) in CSM. In particular, slag rotation allows improving the conditions for equalizing of temperatures through the entire volume of the slag pool and accelerating stabilization of the electroslag process; eliminating formation of microarcs on slag-nonconsumable electrode interface (current-conducting section wall), that prevents fast local wear of the latter; applying discrete materials in electroslag technologies, uniformly distributed over the slag pool surface; thus creating approximately similar conditions for filler granules melting in the slag. Active movement of slag relative to the processed surface should have a positive influence on its sound joining with the surfaced metal.

Proceeding from the requirements made of fluxes (slags) for ESR as the electroslag process closest to ESS of end faces, they are divided into two main groups [7]: technological and metallurgical. Technological requirements include: ease of excitation and high stability of the electroslag process; possibility of achieving moderate rates of metal deposition, guaranteeing axial direction of solidification; minimum specific power consumption; good formation of deposited metal surface; easy separability of the slag crust; stability of slag composition at long-term storage and during ESS; minimum labour consumption in slag manufacture; absence of expensive and deficit components in the slag composition; molten metal protection from air access; ensuring a heat reserve over molten metal, preventing formation of shrinkage cavities and inner cracks in the ingot.

As applied specifically to ESS of end faces in CSM, the following should be added to these requirements: it is desirable to apply relatively low-melting and «long» slags; the slags should have low viscosity and increased fluidity (particularly, for the case of «liquid» start); slag composition should ensure formation of skull of minimum thickness and higher electric conductivity for its «piercing» in the initial period of electroslag process stabilization at relatively low voltage of the power source.

Metallurgical requirements include formation of more ductile nonmetallic inclusions in the deposited metal, preferably of a round shape; higher desulphurizing capacity; and low water permeability.

Since the time of development of the technology of ESS and ESR in a current-supplying mould [8, 9], its different variants have appeared. At present four technological procedures have been proposed on the basis of the known CSM design, namely surfacing and remelting by liquid metal [10, 11]; so-called two-loop circuit of electrode remelting with application of two power sources [12]; surfacing with feeding nonconducting [13] and current-conducting [14] flux-cored wire into the slag pool; surfacing by a two-loop circuit with application of an additional hollow graphite electrode and nonconducting billet (wire) [15].

We are not considering the advantages and disadvantages of newly proposed methods of surfacing in CSM in this paper. We will just consider the interrelation of the surfacing procedure and flux (slag) applied for it in terms of the possibility of providing a stable rotation of the slag pool.

First of all, it should be noted that the issues of slag pool rotation in all these procedures are not considered, just the technological features of the process are assessed. But as the electroslag process proper and movement of slag flows, occurring at its realization, are one electro-physico-chemical phenomenon, we should first of all understand, what are the reasons behind selection of flux for a particular proposed process of surfacing (remelting), and to what extent the criteria of this selection can be used for solving the posed task of ESS with discrete filler with provision of active rotation of the slag pool.

Based on available information, selection of flux for each proposed surfacing procedure either has some substantiation, or just flux of a known grade is used for surfacing.

ANF-94, ANF-32, AN-75 fluxes [10, 11] and different compositions based on fluorides and oxides are used for surfacing with liquid metal, depending on the deposited metal. The main difference of ESS with discrete material from liquid filler consists in that in the first case cold filler granules are fed into the slag pool, and in the second case these are portions of overheated metal. Temperature conditions of slag pool existence and physical properties of slag both in each local zone of the pool, and in its entire volume will differ in these technologies, respectively. Therefore, the flux, used in one surfacing procedure, will not necessarily be suitable for another one, particularly in terms of creation of an active rotary effect in the slag pool.

As regards surfacing with feeding of a small volume of current-conducting or nonconducting wire into the slag pool [13, 14], application of relatively refractory flux ANF-6, apparently, does not always allow producing a sound joint of the base and deposited metals, and the surfacing process proper, as claimed by developers of the procedure, should be conducted in a narrow range of applied electric power. Apparently, for this reason, the authors started performing all the subsequent operations with the same flux, but with additional feeding of a hollow graphite electrode of a special shape of the working edge into the central part of the slag pool [15]. In this case, the entire volume of the slag pool (particularly under the electrode) is heated quite well. So far, just surfacing of end faces of cylindrical parts of relatively small diameter of 30–90 mm (mainly, about 30 mm diameter) has been checked. Applicability of this flux for surfacing larger diameter items and with feeding discrete filler into the slag pool causes some doubt.

Electrode remelting by a two-loop circuit [12], similar to surfacing with liquid filler, allows providing a more uniform thermal field in the slag pool, that, naturally, does not meet the conditions of ESS with discrete filler. Therefore, for this procedure, the requirements to flux selection will be somewhat different, more stringent.

Proceeding from the above, as well as taking into account the earlier performed research [16], assessment of the influence of slag composition on angular speed of slag pool rotation was performed on ANF-29, ANF-32 and AN-26 fluxes. Alongside the established technological capability of application of these fluxes, their potential as a liquid slag environment, capable of rotating during surfacing at feeding surfacing discrete filler on its surface, should be evaluated.

Procedure of experiment performance was assumed to be similar to the one described in [16]. The distance from the processed end face of the billet to the upper edge of forming section L changed gradually from the initial one equal to 94 mm (70 mm for AN-26 flux), to smaller dimensions due to feeding of remelted steel shavings into the slag pool, for building-up the deposited layer at the billet end face, respectively. Slag pool rotation in the horizontal plane was assessed by lowering onto its surface small pieces

Influence of the fraction of current *I* (%) in electric power *N* applied to the slag pool on the speed of slag pool rotation *n*

Flux	Surfacing mode, kA		*n*, rpm	*I* fraction in *N*, %
	I, kA	*N*, kW		
ANF-29	1.34 0.82	52.4 50.8	36 25	2.64 1.56
ANF-32	2.00 1.93	44.0 42.5	48 46	4.55 4.54
AN-26	2.06 1.77	98.9 72.9	40 24	2.08 2.43

of charcoal and measuring their angular displacement with a stopwatch. Average value from three to five tests was taken as the measurement result. A greater number of measurements were conducted at low speeds of pool rotation (lower heat saturation of slag), because of formation of local cooling zones on its surface, preventing stable rotation of charcoal pieces.

Influence of electric power *N* applied to the pool and surfacing current *I* on slag pool rotation was assessed separately. Measurement results are given in Figures 1 and 2.

Analysis of these results leads to the following conclusions.

For ANF-29 and ANF-32 fluxes with relatively similar chemical composition, change of the speed of slag rotation *n* depending on the value of electric power *N* applied to the slag pool at the stage of its formation and stabilization of the electroslag process (L = 94 mm), differs markedly (see Figure 1). For ANF-29 flux direct dependence *N*-*n* approximately corresponds to proportional relationship (at *N* change from 50 to 60 kW *n* changes from 25 to 30 rpm). At the same time, similar to ANF-32 flux, under the same conditions (IV stage of the power source, L = 94 mm) of experiment performance power change from 60 to 80 kW (about 33 %) leads to angular speed of slag pool rotation changing from 7 to 9 rpm (approximately 29 %).

After minimum *L* values have been achieved (due to feeding shavings to the slag pool and deposited layer building-up: 22 mm for ANF-29, 28 mm ANF-32, and 25 mm for AN-26, respectively), gradual transition from power source IV stage to lower stages (III and II) was performed. At these *L* values the inclination of straight lines for ANF-29 and ANF-3 fluxes becomes similar. *N*-*n* dependence for AN-26 flux is characterized by a more abrupt change of *n* at reduction of the applied electric power.

As noted above, formation and speed of slag pool rotation are determined, chiefly, by working currents of surfacing. And although the trend of direct dependencies of *N*-*n* and *I*-*n* is approximately the same (see Figures 1, 2), the influence of current component in

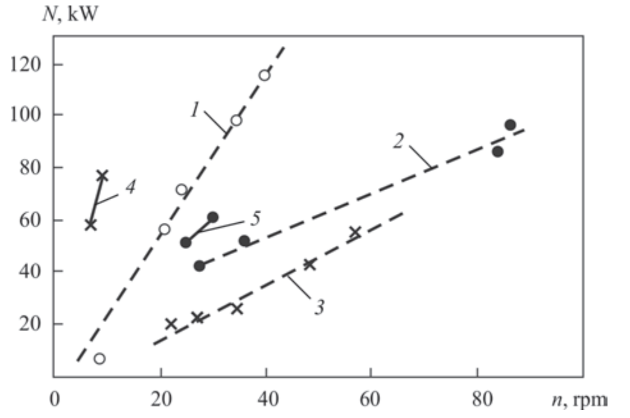

Figure 1. Influence of electric power *N* applied to the slag pool on its rotation speed *n*: *1* — AN-26; *2* — ANF-29; *3* — AHF-32; *4* — ANF-32 (L = 94 mm); *5* — ANF-29 (L = 94 mm)

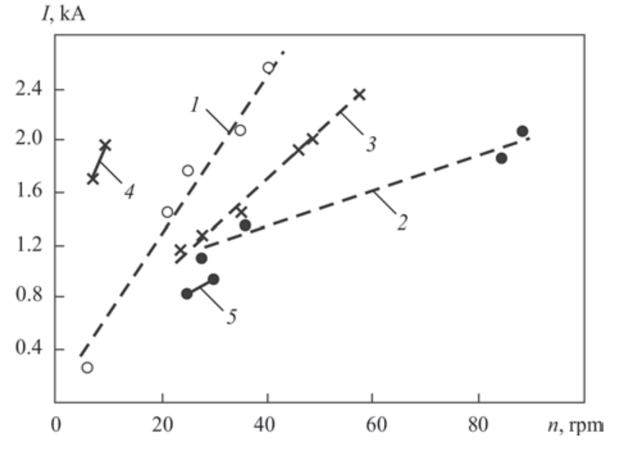

Figure 2. Influence of surfacing current *I* on speed *n* of slag pool rotation (designations are the same as in Figure 1)

the electric power applied to slag of different chemical composition can be assessed, proceeding from the following data (Table).

Conclusions

1. Ensuring optimum rotation of the slag pool, both in the initial period of its formation (characterized by the time, required for minimum angular movement of the melt around the mould perimeter), and at stabilization of the electroslag process (unchanged value of surfacing current before feeding the filler into the slag pool, constant speed of pool rotation, fast immersion of the filler into the slag pool without formation of conglomerates of slag and surfacing material on its surface) is an important characteristic of fluxes, applied for ESS in the current-supplying mould.

2. Angular speed of slag pool rotation depends both on electric power, applied to it during performance of electroslag process in CSM, and directly on surfacing working current. Surfacing current plays the most significant role in this effect.

3. Of the three fluxes considered in the experiments the best conditions for performance of slag pool rotation can be obtained, when using ANF-29 flux. Slag

pool set when melting ANF-29 flux, allows achieving sufficiently high rotational effect both in the period of slag pool formation, and during the surfacing process. ANF-32 flux is similar to ANF-29 flux as to its ability to rotate the slag pool, when conducting a stable electroslag process, but it is less effective during slag pool formation. AN-26 flux can provide active rotation of the slag pool during surfacing, but it requires application of higher electric power to it.

1. Vachugov, G.A., Chumanov, V.I., Khasin, G.A. et al. (1975) Influence of rotation of remelted electrode on electroslag remelting process. *Problemy Spets. Elektrometallurgii*, **28**, 31–36 [in Russian].
2. Kodama, H., Kandro, I., Akahori, K. et al. (1987) Properties of cladded rolls produced by method of electroslag surfacing with rotation. In: Proc. of 8th Intern. Conf. on Vacuum Metallurgy, S*pecial Kinds of Surfacing and Metallurgical Coatings*, **9**, 139–145.
3. Maksimovich, B.I. (1962) Effect of electromagnetic rotation of slag pool on crystallization of metal in electroslag remelting of high-alloy steels and alloys. *Elektrotermiya*, **5**, 9–12 [in Russian].
4. Topilin, V.V., Klyuev, M.M., Fomicheva, N.P., Grebtsov, Yu.G. (1968) Refining of macrostructure of ingots in electroslag remelting of alloys. *Problemy Spets. Elektrometallurgii*, **1**, 23–28 [in Russian].
5. Kudelkin, V.P., Klyuev, M.M., Filippov, S.I. et al. (1969) Impact of ultrasonic oscillations on crystallization in electroslag remelting. *Izv. Vuzov. Chyorn. Metallurgiya*, **11**, 64–70 [in Russian].
6. Ksyondzyk, G.V. (1975) Current-supplying mold insuring rotation of slag pool. *Problemy Spets. Elektrometallurgii*, **27**, 33–40 [in Russian].
7. Podgaetsky, V.V., Kuzmenko, V.G. (1988) *Welding fluxes:* Refer. Book. Kiev, Naukova Dumka [in Russian].
8. Ksyondzyk, G.V., Frumin, I.I., Shirin, V.S. (1964) *Current-supplying mold*. USSR author’s cert. 264427 [in Russian].
9. Ksyondzyk, G.V., Frumin, I.I., Shirin, V.S. (1969) *Device for electroslag remelting*. USSR author’s cert. 337026 [in Russian].
10. Kuskov, Yu.M. (1969) Electroslag surfacing of cylindrical billets with liquid filler material in current-supplying mold. *Avtomatich.Svarka*, **6**, 52–53 [in Russian].
11. Medovar, B.I., Chernets, A.V., Medovar, L.B. et al. (1995) Electroslag surfacing with liquid filler metal. *Problemy Spets. Elektrometallurgii*, **1**, 6–11 [in Russian].
12. Tsykulenko, A.K., Lakuman, I.A., Medovar, L.B. et al. (2000) Two-loop circuit of electroslag remelting of consumable electrode. *Ibid.*, **3**, 16–20 [in Russian].
13. Sokolov, G.N., Lysak, V.I. (2005) *Surfacing of wear-resistant alloys on press tools and instruments for hot forming of steels*. Volgograd, RPK Politekhnik [in Russian].
14. Sokolov, G.N. Zorin, I.V., Tsurikhin, S.N. (2004) Technology of electroslag surfacing of mandrels of tube-rolling unit. *Svarshchik*, **1**, 15 [in Russian].
15. Sokolov, G.N. (2007) *Formation of composite structure of deposited metal for operation in thermoslag impact conditions and development of ESS of press tools and instruments*: Syn. of Thesis for Dr. of Techn. Sci. Degree. Volgograd [in Russian].
16. Kuskov, Yu.M. (2018) Influence of flux composition on the process of electroslag surfacing of end faces with discrete feeding of filler material. *The Paton Welding J*., **1**, 33–37.

Received 12.01.2018