doi.org/10.15407/tpwj2018.01.07

INFLUENCE OF FLUX COMPOSITION ON THE PROCESS OF ELECTROSLAG SURFACING OF END FACES WITH DISCRETE FEEDING OF FILLER MATERIAL

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Applicability of fluxes of different grades at electroslag surfacing of end faces by discrete filler material in a current-supplying mould was studied. It is found that selection of fluxes proceeding just from their physical properties (viscosity and electrical conductivity) does not guarantee the conditions required for conducting the electroslag process. Optimum position of the billet end face to be surfaced in the mould working cavity is very important for normal operation of the mould and performance of sound surfacing with good formation of the deposited metal. In view of the above-said, ANF-29, ANF-32, ANF-26 fluxes can be used for electroslag surfacing with discrete material. 20 Ref., 2 Tables, 4 Figures.

Keywords: *electroslag surfacing of end faces, flux, discrete filler, current-supplying mould, current, voltage, process stability*

Current-supplying mould (CSM) is a structure of sectioned type, combining the functions of nonconsumable electrode and device forming the deposited metal [1, 2]. It can be used both for electroslag surfacing (ESS), and electroslag remelting (ESR). Electrodes and billets of a large cross-section, wire, strip, solid and liquid fillers can be used as material fed into the liquid pool. Application of discrete filler seems to be the most promising, as it not only forms the deposited layer, but can have an inoculating impact on the solidifying metal structure.

Schematic of ESS of end faces with discrete filler in CSM is shown in Figure 1.

CSM is used as a mobile device, or it is mounted stationary with displacement of the layer being deposited relative to it. At deposition of relatively thin layers (approximately ≤90 mm) CSM can be used without relative displacement of the mould and the deposited metal. In this case the forming section of the mould should have the height which can accommodate the deposited layer. At layer thickness ≥90 mm, difficulties of heating the whole volume of the slag pool, arise, and metal formation becomes worse. Actual thickness of the layer with good formation is ultimately determined by physico-chemical properties of the applied flux, as well as the kind and chemical composition of the surfacing material. One of the main stages of conducting the electroslag process in CSM is setting the slag pool in it and preservation of its stability (stable chemical composition and specified electrical parameters of the process) during the entire period of CSM operation. The slag pool can be set in the mould with application of one of the two known techniques — liquid or solid start. In a regular mould, slag pool of optimum depth (40–100 mm) is formed by one-time pouring of the required portion of slag into it from flux-melting furnace, or the same slag volume is obtained by shorting the consumable or nonconsumable electrode on the tray (or billet being surfaced) with gradual increment of molten flux quantity, transferring the process form the arc to the slag one.

In CSM the poured-in slag portion can have different volume, depending on the position of the billet or tray, relative to current-conducting section of the

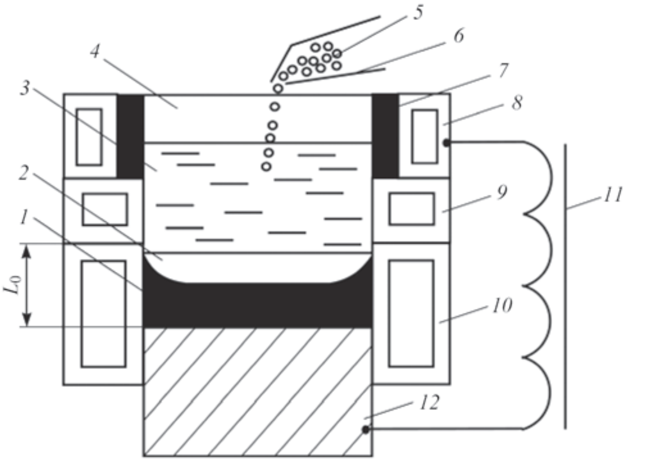

Figure 1. Schematic of ESS of end faces with discrete filler in CSM: *1* — deposited metal; *2* — metal pool; *3* — slag pool; *4* — mould; *5* — filler metal feed mechanism; *6* — discrete filler material; *7* — protective layer (molybdenum, tungsten and graphite); *8–10* — mould sections; *11* — transformer; *12* — billet

mould. The situation is similar also when performing the solid start, when the slag pool volume should be sufficient for closure of the electrical circuit of current-conducting section–slag–tray (or billet). This closure is exactly what allows ensuring CSM normal operation and conducting the electroslag process for a sufficiently long time without adding any additional devices or electrodes into the working zone for maintaining the slag pool in the molten state.

It should be also noted that, depending on the electric mode of surfacing and slag properties, the slag pool surface can vary considerably, and this, alongside the earlier mentioned influence of the slag pool thermal condition on surfacing quality, may lead to formation of non-conducting or partially current-conducting slag skull (solid or half-liquid crust) on the working surface of the current-conducting section, even in the case, when it is protected by electrically conducting lining, most often graphite one. Appearance of skull makes current passage through one of the working electric circuit elements difficult, process stability is disturbed; in the extreme case, the electroslag process stops completely.

Thus, correct selection of the flux (slag) is of paramount importance for normal CSM operation. Flux cost should be also taken into account. It is known that the flux cost is equal to 2–6 % in the cost of melting ESR ingots [3]. At ESS, when relatively small metal layers are mainly deposited, this value naturally becomes much greater.

From the moment of electroslag process invention at the end of 1940s – beginning of 1950s more than 50 flux grades have been proposed for its performance. The main component of the fluxes is calcium fluoride, characterized by the lowest vapour pressure at the temperatures of electroslag processes, compared to Al, Ba, Mg fluorides. Physical properties of molten CaF_2 ensure process stability.

Ca, Al, Mg oxides are added to reduce electrical conductivity, adjust melt viscosity, and improve its desulphurizing ability. Content of silica as a compound, which is less thermodynamically stable one than the above-mentioned oxides, and also lowers the desulphurizing ability of slag, is usually not higher than 2 %. However, at ring ESS, as well as in practical application of ESR, fluxes with increased silica content (ANF-14, ANF-25, ANF-28, ANF-29) are sometimes used.

At present, fluxes of different grades are used for conducting the electroslag process, depending on chemical composition of the metal being remelted, its kind and surfacing technique (in a mobile or stationary mould). The following examples of such an approach to selection of fluxes for operation with CSM can be given: ring ESS by liquid metal (chromium cast irons, stainless, tool, high-speed steels, etc.) with relative displacement of the deposited metal and mould with application of AN-75, ANF-32, ANF-94 fluxes [4–7]; remelting of electrodes and surfacing of end faces (titanium alloys, copper, low-alloyed and stainless steels) with CaF_2, ANF-94, ANF-28 fluxes [8–10]; ESR, end face and ring surfacing with feeding into the slag pool (ANF-14, AN-75, ANF-29, ANF-28N) discrete fillers (chromium and chromium-nickel cast irons, high-speed and die steels, copper, etc.) [4, 10–13].

The influence of some process parameters and chemical composition of fluxes on the stability of the electroslag process in CSM at ESS of end faces with discrete filler is considered in this work. In this case, alongside good formation of the deposited metal from the very start of surfacing and complete melting of the filler, it is also necessary to ensure sound joining of the base and deposited metal, using the correctly selected flux. The latter is a rather complicated task, compared, in particular, to ESR method, in which the removed (bottom) part of the ingot may reach 15 % of its weight [14]. Therefore, this task will be considered in the following papers.

Fluxes, which were accepted both in electroslag and in arc processes (AN-22, AN-26) were selected for preliminary consideration. Flux grades and their composition according to TU specification are given in Table 1.

Table 1. Fluxes, pre-selected for consideration of their applicability in the investigations

Flux grade	Chemical composition of fluxes, wt.%					
	CaF_2	Al_2O_3	CaO	SiO_2	MgO	MnO
ANF-14	60–65	10–12	≤ 8	14–16	4–8	–
ANF-29	37–45	13–17	24–30	11–15	2–6	–
ANF-32	34–42	24–30	20–27	5–9	2–6	–
ANF-94	34–40	17–21	11–22	14–20	7–11	≤ 2
AN-75	56–59	9–12	6–8	18–21	6–8	5–7
AN-90	39.0	10.5	23.5	26.5	0.5	–
AN-22*	20–24	19–23	12–15	18–22	12–15	7–9
AN-26	20–24	19–23	4–8	29–33	15–18	2.5–4

*Flux additionally contains $Na_2O + K_2O$ in the amount of 1.3–1.7 wt.%.

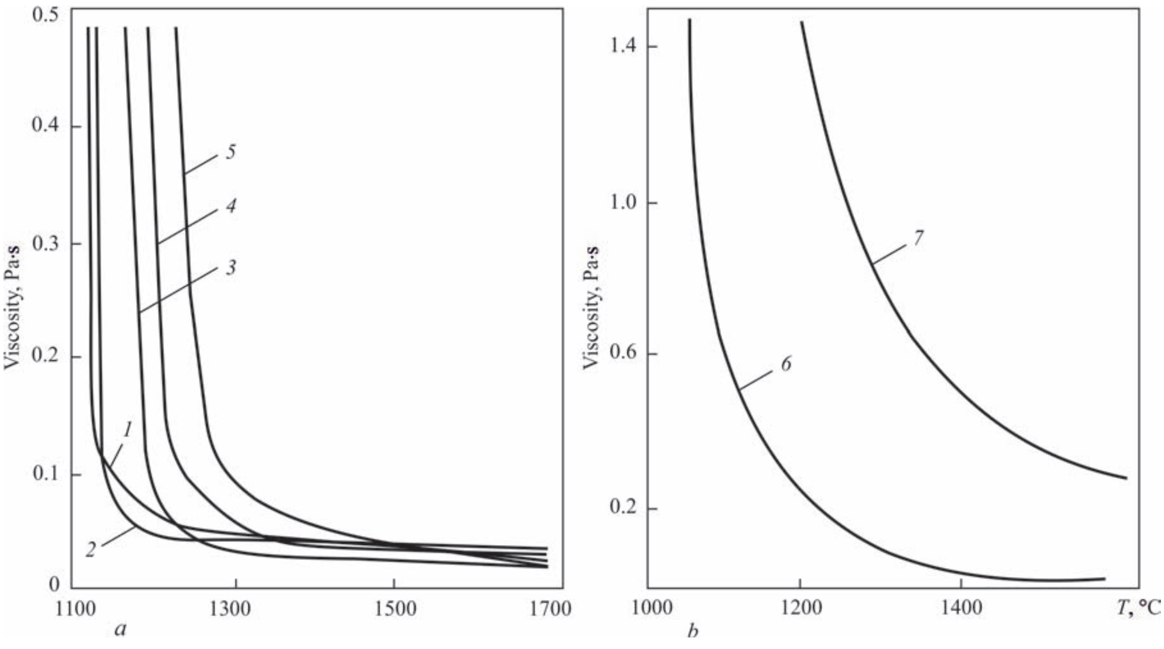

Figure 2. Dependence of flux viscosity on temperature [15–18]: *a* — salt-oxide; *b* — oxide fluxes: *1* — ANF-14; *2* — AN-75; *3* — ANF-29; *4* — ANF-32; *5* — ANF-94; *6* — AN-22; *7* — AN-26

Dependencies of the main physical characteristics of slags, namely viscosity and electrical conductivity, on temperature are given in Figures 2 and 3 [15–18]. There is no data on physical properties of AN-90 flux.

The main technical and economic characteristics of electroslag processes, and, accordingly, criteria for flux selection, were as follows:

Oxide-fluoride flux ANF-14 is used at electroslag welding of steels, as well as in ESS of cast irons, in particular, ESS by an electrode – pipe of hot rolling rolls [4]. At ESS with cast iron shot in CSM, slag inclusions were observed in the deposited metal and along the fusion boundaries of the base and deposited metal in a number of cases. This is associated with the cooling impact of shot fed into the slag pool, in contrast to that of overheated drops from the melted off consumable electrode tip. It is not produced commercially.

ANF-29 and ANF-32 fluxes are designed for ESS in mobile moulds, due to addition of an increased quantity of SiO_2 to their composition [19]. Presence of an increased content of silica in slag based on calcium fluoride, promotes producing a thin skull crust and good formation of the deposited surface in a wide range of variation of the melting modes. These fluxes are produced commercially.

ANF-29 flux. It was developed for ring ESS by liquid metal (high-speed steels) in CSM [10]. Similar to the case of ANF-14 flux, conditions of slag pool existence differ considerably at feeding the liquid and solid filler. It is not produced commercially.

AN-75 flux. It is a modification of ANF-14 flux due to addition of 5–7 % MnO to it. At ESS with cast iron shot in a mobile CSM, it provides good formation of cast iron and fusion of the base (steel, cast iron) and deposited metals [4]. At deposition of steel shot metal formation deteriorates, and unmolten shot particles occur in the deposited layer. It is not produced commercially.

AN-90 flux. It was developed for ESS by stainless steel strips with free formation of the deposited metal. It provides good metal formation, easy detachment of

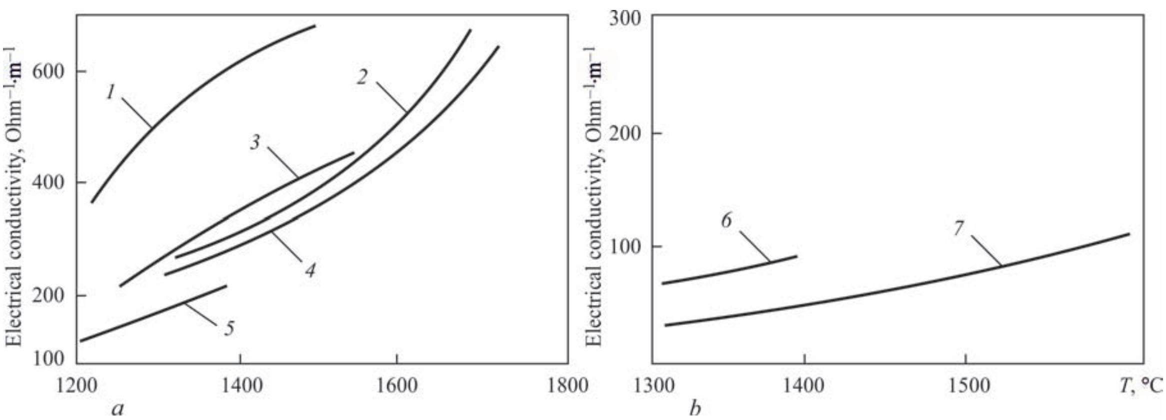

Figure 3. Dependence of flux electrical conductivity on temperature [15–18]: *a* — salt-oxide; *b* — oxide fluxes: *1* — AN-75; *2* — ANF-29; *3* — ANF-32; *5* — ANF-14; *6* — AN-22; *7* — AN-26

Table 2. Electrical characteristics (I, kA, U, V) of surfacing of end faces with discrete filler at certain position (L, mm) of the deposited layer

Flux grade	Measured parameters	Evaluation levels											
		1	2	3	4	5	6	7	8	9	10	11	12
ANF-29	L	0	88	82	76	70	64	58	52	46	40	34	28
	I	0.98	1.55	1.97	2.04	2.05	2.26	2.30	2.38	2.46	2.6	2.68	2.73
	U	62.6	59.2	57.0	56.6	56.4	55.6	55.5	55.1	54.7	53.8	53.5	54.4
ANF-32	L	0	88	82	76	70	64	58	52	46	40	34	28
	I	1.56	1.69	1.77	1.83	1.87	2.0	2.15	2.26	2.42	2.58	2.8	2.84
	U	34.5	43.8	42.6	42.6	41.5	40.0	37.6	34.4	34.2	31.2	30.2	27.3
AN-26	L^*	0	65	60	55	50	45	40	35	–	–	–	–
	I	2.33	2.44	2.54	2.56	2.72	2.83	2.95	3.16	–	–	–	–
	U	57.3	57.2	56.6	56.6	55.6	54.8	54.5	53.4	–	–	–	–

$^*L_0$ = 70 mm.

the slag crust, maintaining a stable electroslag process at a small depth of the slag pool, low susceptibility to hydratation [20]. It is not commercially produced.

AN-22 flux. It is used both for electric arc welding, and for high-alloyed steel surfacing. A relatively low content of highly deficit CaF_2 can be regarded as the advantage of this flux. It is not produced commercially.

AN-26 flux. Its application and advantages are similar to those of AN-22 flux. It is produced commercially in the vitreous variant (AN-26S).

As a result of the performed analysis, ANF-29, ANF-32, AN-90, AN-22 and AN-26 fluxes were selected for investigations. Application of AN-90 and AN-22 fluxes caused the greatest doubt. The first one — for the reason of lack of understanding of its behaviour at ESS in water-cooled moulds, the second one — because of presence of about 2 % of sodium and potassium oxides in its composition, that supposedly would hinder preservation of their content during surfacing.

In this connection, investigations were divided into two stages. At the first stage practical verification of stabilization of electroslag process with AN-22 and AN-90 fluxes was performed at ring ESS in CSM with a widened upper section and increased diameter of the surfaced billet. Such a surfacing schematic allowed reducing the slag pool volume (2870 cm^3) to improve its preheating conditions. But in this case, too, after pouring each of these slags into the mould (liquid start), it was not possible to set a stable slag pool, even at maximum level of the power source.

Figure 4. Appearance of side surface of the deposited layer with application of AN-26 flux at initial value of L_0 equal to 70 mm (longitudinal section of the deposited billet)

Therefore, the main investigations (stage 2), were conducted with application of ANF-29, ANF-32 and AN-26 fluxes at surfacing of end faces in a smooth-bore CSM with 3820 cm^2 volume of the slag pool (approximately by 30 % greater than in experiments of the 1st stage). Procedure of experiment performance was as follows (see Figure 1). In CSM of 180 mm diameter, the water-cooled electrode with a graphite attachment at its end was used to set a slag pool on the billet surface, by successively melting flux portions, until the pool began touching the current-conducting section of the mould. From this moment, CSM operation began, and the electrode was removed from its working cavity. After preheating the slag pool for three minutes, dry fine chips (after milling) of the following chemical composition, wt.%: 0.50 C; 0.62 Si; 1.3 Mn; 3.30 Cr; 0.93 Ni; 0.15 Mo; ~ 1.0 Cu, were fed into it in portions. Prior to that, chips weight to which a certain deposited layer thickness corresponds, was determined. All the surfacing operations were performed at the maximum IV level of transformer TShP-10. Initial distance from the processed surface of the billet to the upper edge of the forming section (L_0) was equal to 94 mm.

During surfacing, maximum possible distance from the processed surface of the billet to the edge of forming section (L_0) was determined for each flux (from evaluation levels), as well as currents and voltages, corresponding to each position of the deposited metal level.

Results of the performed experiments are shown in Table 2. Analysis of measurement results, technological features of surfacing operations, as well as the values of viscosity and electrical conductivity of fluxes depending on temperature (Figures 2, 3), lead to the following conclusions. Despite the relatively close values of physical properties of ANF-29 and ANF-32 fluxes, their behaviour at surfacing is different. Each feeding of steel chips into the slag pool reduced the distance from the deposited layer surface to the current-conducting section, thus lowering the electrical resistance in the section-slag-deposited metal segment. Here current rises and for ANF-29 flux, approximately at the third evaluation level, the slag pool already actively rotates in the horizontal plane, quietly absorbing the fed portions of the filler. At application of ANF-32 flux, the weight of the first portions of chips had to be minimized, as the thermal power of the slag pool was insufficient for melting large portions of filler. When attempting to increase their mass feed rate, the chips significantly impaired the process stability, because of lowering of slag temperature. And only after achievement of approximately level 4–5 the process was completely stabilized. Therefore, for ANF-32 flux the initial L_0 value should be equal to about 70–75 mm.

Considering the physical properties of AN-26 flux (relatively low electrical conductivity, increased viscosity and melting temperature), it was decided to conduct the experiments at initial value L_0 = 70 mm. For these surfacing conditions the slag pool formed due to melting of AN-26 flux, is set without any difficulties, even at level II of the power source. At surfacing proper (level IV of the power source) the chips were actively melting in the slag, which had a higher temperature at visual evaluation. Correctness of selection of initial value L_0 was confirmed by that the side surface of the deposited layer, corresponding to feeding chips on level 1–2, was slightly worse formed than on the other levels (Figure 1).

Conclusions

1. At ESS of end faces with discrete filler in CSM the specific conditions of CSM operation make special requirements not only to physical properties of fluxes, but also to laying out the mould working space (arrangement of the billet to be surfaced in it).

2. Selection of fluxes proceeding just from their physical properties, does not guarantee optimum conditions of conducting the electroslag process at ESS in CSM.

3. «Long» ANF-29 and ANF-32 fluxes are suitable for performing ESS of end faces in both mobile and stationary CSM. «Short» AN-26 flux can be used in the technologies of surfacing without relative displacement of the mould and surface billet. In both the cases, stable electroslag process and good formation of the deposited metal are ensured at optimum positioning of the processed end face in CSM working cavity.

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Received 12.09.201