

EFFECT OF FLUX COMPOSITION ON THERMAL-PHYSICAL AND PHYSICAL-CHEMICAL PROCESSES IN LIQUID-METAL ELECTROSLAG SURFACING

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The effect of fluoride silicon-free fluxes ANF-6, ANF-25 and ANF-1P, and low-silicon fluxes AN-15 and AN-15M on thermal-physical and physical-chemical processes occurring in liquid-metal electroslag surfacing (LMESS) of dies was assessed. Experimental results allow a conclusion that flux AN-15M is most preferable for LMESS of forming dies. It allows rapid and uniform melting of the surfaces of dies, as well as keeping the composition of the deposited metal almost unchanged, compared to the initial metal of steel 5KhNM chips at up to 50 % desulphurisation degree.

Keywords: *electroslag surfacing, dies, liquid metal, thermal-physical processes, carbonisation, desulphurisation*

The possibility of providing a sound joint in liquid-metal electroslag surfacing (LMESS) depends in many respects on thermal-physical properties of the applied flux, which determine stability of the electroslag process, character of distribution of the electric current in the slag pool, intensity of heat release in it and heat transfer to the metal pool, duration and uniformity of heating of the base metal surface, and degree of its cleaning from oxides [1].

In addition, during LMESS the slag, deposited metal and graphite of non-consumable electrodes, which support the electroslag process, interact between each other for quite a long time at high temperatures (up to 1900 °C). This may lead to a substantial change in composition and properties of both slag and deposited metal, which is inadmissible.

It is a known fact that the use of basic fluxes allows the liquid metal to be refined [2]. However, this may lead to carbonisation [3]. The degree of carbonisation grows with increase in the content of calcium oxide, and decreases with increase in the concentration of silica in slag [4, 5]. According to the data of study [4], when adding 15–20 % SiO₂ to slag of the CaF₂–Al₂O₃–CaO system no carbonisation takes place, and refining properties of the slag remain good. Also, it is noted that the equilibrium content of carbon in the liquid metal depends on its composition [6].

Therefore, the task of this study was to assess the effect of various fluxes on thermal-physical and physical-chemical processes in ESS that cause a change in the composition of metal and slag, as well as to determine the most suitable flux for the LMESS process.

Fluoride silicon-free fluxes ANF-6, ANF-25 and ANF-1P, as well as low-silicon fluxes AN-15 and AN-15M were chosen for the study (Table 1). Temperature dependences of viscosity and elec-

Table 1. Standard chemical composition of fluxes under investigation, wt.%

No.	Flux grade	CaF ₂	CaO	Al ₂ O ₃	SiO ₂	MgO	MnO	Fe ₂ O ₃	S	C
1	AN-15	20–23	14–18	22–25	24–29	8–11	1.5–2.5	≤ 0.85	≤ 0.05	–
2	AN-15M	16–20	29–33	36–40	6–10	≤ 2	≤ 0.9	≤ 0.8	≤ 0.07	–
3	ANF-1P	≥ 90	≤ 5	≤ 3	≤ 2.5	–	–	≤ 0.5	≤ 0.05	≤ 0.1
4	ANF-6	Base	≤ 8	25–31	≤ 2.5	–	–	≤ 0.5	≤ 0.05	≤ 0.1
5	ANF-25	50–60	10–15	12–20	2–7	10–15	–	≤ 0.5	≤ 0.07	≤ 0.1

Note. Flux AN-15M may contain 2.0–5.5 % NaF.

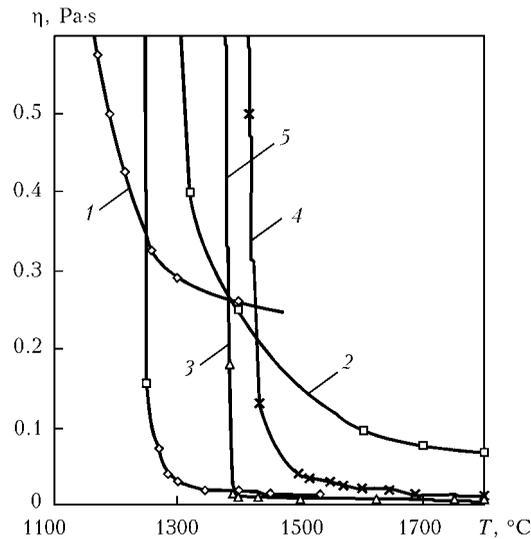


Figure 1. Dependence of viscosity of fluxes on temperature: 1-4 – here and below the grades of fluxes correspond to those given in Table 1

trical conductivity of these fluxes are shown in Figures 1 and 2 [7-9].

The experiments were conducted at the E.O. Paton Electric Welding Institute by using machine A-550 and at the Tokmaksky Press-Forging Factory by using machine OB-2213 for surfacing of 5KhNM steel billets of different standard sizes with liquid steel of the same grade.

Preliminarily the molten flux, i.e. slag, was poured on the surface of a solid billet (forging, worn-out die) placed in a copper water-cooled mould, and electroslag heating of the billet up to its incipient melting was performed by using graphitised electrodes. Then the liquid metal melted in an induction furnace was poured on the thus prepared surface through a layer of the molten slag. After pouring of the required amount of metal, it was solidified under the slag layer by gradually decreasing the power of the electroslag process.

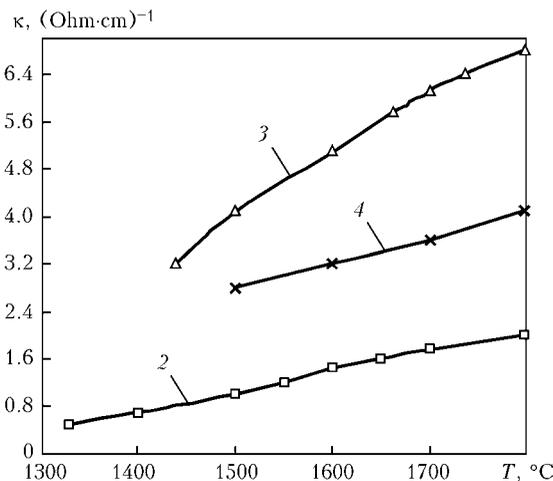


Figure 2. Dependence of electrical conductivity of fluxes on temperature

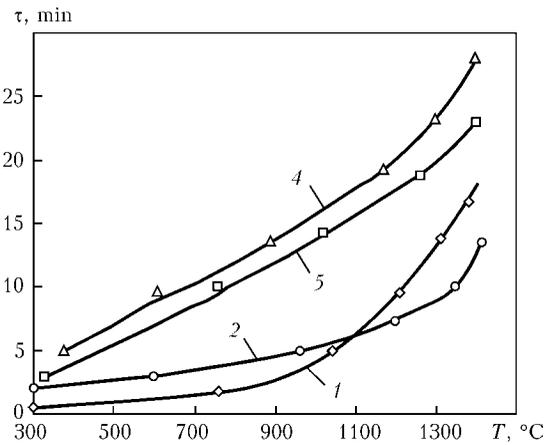


Figure 3. Intensity of electroslag heating of surfaces of dies measuring 210 × 210 × 50 mm (specific power 150·10⁴ W/m², voltage 35 V)

In ESS the temperature of the slag was maintained within 1550-1800 °C, the depth of the slag pool being 50-60 mm. The slag temperature was measured by using a tungsten-rhenium thermocouple with a tip of boron carbonitride. The temperature of the billet being surfaced was measured at the centre and at the ends by using the similar thermocouples caulked under its surface at a depth of 5 mm. Samples for chemical analysis of metal and slag were taken before and after the experiment.

As shown by the experiments, in case of using more conducting fluoride fluxes ANF-1P, ANF-6 and ANF-25 the electroslag process performed under the same conditions as in case of using the low-silicon fluxes was unstable, and often changed into the arc one. This phenomenon aggravated with increase in voltage, and became particularly pronounced when using flux ANF-1P, which has the highest electrical conductivity. Moreover, it was hard to regulate gradually because of a dramatic change in the electric current with deepening of electrodes into the slag pool. Therefore, in the case of using the fluoride fluxes, to provide gradual regulation of the current and improve stability of the process it should be performed at a deeper slag pool than in the case of using the low-silicon fluxes.

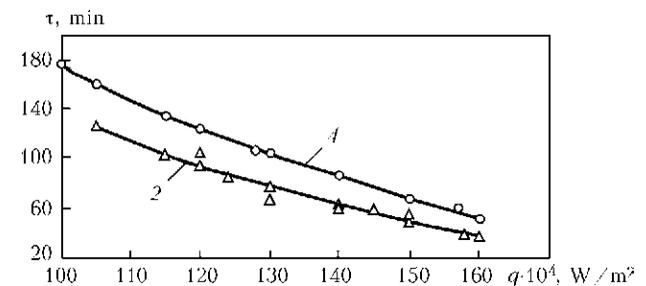


Figure 4. Effect of specific power q on duration of electroslag heating of die billets measuring 400 × 200 × 180 mm up to incipient melting

Table 2. Changes in chemical composition of deposited metal during the LMESS process depending on the flux grade

Type of deposited metal	Flux grade	Weight content of elements and its relative change η_E , %							
		C	η_C	Si	η_{Si}	Mn	η_{Mn}	S	η_S
Steel 5KhNM	AN-15	$\frac{0.58}{0.59}$	+1.7	$\frac{0.41}{0.53}$	+29.3	$\frac{0.48}{0.65}$	+35.4	$\frac{0.025}{0.020}$	-20
	AN-15M	$\frac{0.55}{0.56}$	+1.8	$\frac{0.40}{0.39}$	-2.5	$\frac{0.52}{0.53}$	+1.9	$\frac{0.023}{0.013}$	-43.5
	ANF-1P	$\frac{0.55}{0.63}$	+14.5	$\frac{0.21}{0.01}$	-95.2	$\frac{0.55}{0.19}$	-65.5	$\frac{0.019}{0.009}$	-52.6
	ANF-6	$\frac{0.52}{0.58}$	+11.5	$\frac{0.37}{0.16}$	-56.8	$\frac{0.58}{0.29}$	-50	$\frac{0.025}{0.015}$	-40.0
	ANF-25	$\frac{0.52}{0.55}$	+5.8	$\frac{0.33}{0.18}$	-45.5	$\frac{0.61}{0.29}$	-52.5	$\frac{0.021}{0.009}$	-57.1
Steel 5KhNM (DSTU 3953-2000)	-	0.5-0.6	-	0.1-0.4	-	0.5-0.8	-	≤0.03	-

Notes. 1. $\eta_E = \frac{([E_{end}] - [E_b])}{[E_{end}]} \cdot 100$ %, where $[E_b]$ and $[E_{end}]$ – contents of an element before the beginning and after the end of the process, respectively. 2. Values for $[E_b]$ are given in the numerator, and values for $[E_{end}]$ are given in the denominator. 3. η_C and η_S – degrees of carbonisation and desulphurisation, respectively. 4. Sign «+» means increase in the content of an element, and sign «-» – decrease. 5. As no significant decrease in the contents of chromium, nickel and molybdenum took place, they are not indicated in the Table.

Compared to the more conducting fluoride fluxes, when using the low-silicon fluxes the process of heating of the die surfaces was faster and less power-consuming (Figure 3). This difference was observed in heating over a wide range of specific power values (Figure 4). Lower electrical conductivity of the low-silicon fluxes requires that electrodes be immersed deeper into the slag pool to let pass the required amount of the current. So, it makes it possible to bring the zones of active heat release closer to the surface of the base metal being heated.

The fluxes investigated can be ranked as follows in uniformity of heating of the surface treated: AN-15M, AN-15, ANF-6, ANF-25 and ANF-1P. The difference in temperatures on the die surface (plane size 550 × 380 mm) in heating

before melting under slag AN-15M is 240 °C, and under slag ANF-6 – 400 °C. This is related to the fact that a higher temperature of the slag pool is achieved, and a more intensive stirring of the latter occurs when using the less conducting low-silicon fluxes, thus providing increase in uniformity of heating.

The possibility of rapid and simultaneous setting of the electroslag process at all electrodes, which determines to a considerable degree the uniformity of heating of the billet surfaced, also depends on the thermal-physical properties and composition of a flux applied. When using refractory fluxes, after melting them and pouring into the mould the surface of the slag pool is rapidly covered with a crust, which hampers

Table 3. Change in chemical composition of slag during the LMESS process depending on the flux grade

Flux grade	CaF ₂	CaO	Al ₂ O ₃	SiO ₂	MgO	MnO	Fe ₂ O ₃	S	C
AN-15	$\frac{21.0}{18.9}$	$\frac{17.3}{18.7}$	$\frac{22.7}{22.4}$	$\frac{26.9}{24.9}$	$\frac{9.5}{9.3}$	$\frac{2.40}{2.30}$	$\frac{0.51}{0.44}$	$\frac{0.007}{0.006}$	$\frac{0.030}{0.025}$
AN-15M	$\frac{20.8}{19.8}$	$\frac{29.2}{29.7}$	$\frac{39.3}{37.5}$	$\frac{9.3}{9.9}$	$\frac{0.6}{0.4}$	$\frac{0.20}{0.16}$	$\frac{0.28}{0.37}$	$\frac{0.008}{0.019}$	$\frac{0.040}{0.035}$
ANF-1P	$\frac{90.1}{82.8}$	$\frac{5.0}{6.7}$	$\frac{1.8}{1.6}$	$\frac{2.6}{4.6}$	-	$\frac{0.25}{0.83}$	$\frac{0.11}{0.36}$	$\frac{0.007}{0.014}$	$\frac{0.040}{0.035}$
ANF-6	$\frac{65.5}{62.6}$	$\frac{6.8}{8.6}$	$\frac{28.3}{26.1}$	$\frac{2.6}{5.2}$	-	$\frac{0.16}{0.30}$	$\frac{0.16}{0.29}$	$\frac{0.008}{0.018}$	$\frac{0.035}{0.030}$
ANF-25	$\frac{55.8}{52.6}$	$\frac{13.8}{19.9}$	$\frac{14.2}{11.3}$	$\frac{2.2}{5.2}$	$\frac{12.6}{11.7}$	$\frac{0.29}{0.72}$	$\frac{0.27}{0.45}$	$\frac{0.008}{0.020}$	$\frac{0.040}{0.035}$

Note. The data before the beginning of the process are given in the numerator, and those after the end of the process – in the denominator.

Table 4. Effect of temperature and composition of slag on the processes of carbonisation and desulphurisation of metal in LMESS

Flux grade	Slag temperature, °C	Weight content of carbon and carbonisation degree η_C , %*				Weight content of sulphur and desulphurisation degree η_S , %**			
		Distance from surface, mm							
		Initial	3	10	90	Initial	3	10	90
ANF-6	1550	0.52	0.58 (11.5)	0.53 (1.9)	0.52	0.025	0.015 (40)	0.018 (28)	0.025
	1750	0.59	0.72 (22)	0.61 (3.4)	0.59	0.021	0.011 (47.6)	0.013 (38.1)	0.023
AN-15M	1550	0.55	0.56 (1.8)	0.55	0.55	0.023	0.013 (43.5)	0.016 (30.4)	0.023
	1800	0.58	0.60 (3.4)	0.59 (1.7)	0.58	0.020	0.010 (50)	0.012 (40)	0.020

* Values of carbonisation degree are given in brackets. ** Values of desulphurisation degree are given in brackets.

deepening of electrodes and inhibits setting of the electroslag process.

In case of using lower-melting point fluxes these operations are easier to perform. For the fluxes under investigation the possibility of rapid setting of the electroslag process grows in the following sequence: ANF-1, ANF-6, AN-15M and AN-15.

Analysis of the deposited metal shows that substantial changes in chemical composition of the deposited metal took place during the process as a result of interaction with fluoride fluxes ANF-1P, ANF-6 and ANF-25 (Table 2). For example, the compositions of sulphur, silicon and manganese decreased, and the composition of carbon increased. The most significant changes in composition of metal as to its content of carbon, silicon and manganese were noted in case of using flux ANF-1P containing 95 % CaF_2 . When using flux AN-15, reduction of silicon and manganese takes place, and their contents in metal grows by 30–35 %. The degree of desulphurisation and carbonisation of metal is not high, which is in good agreement with the known data [4].

When using flux AN-15M, the contents of carbon, silicon and manganese in the deposited metal remain almost unchanged. At the same time, the content of sulphur decreases approximately by 44 %. The above changes in chemical composition of metal are in agreement with the corresponding changes in the composition of slag during the surfacing process (Table 3).

For instance, whereas with the fluoride fluxes the contents of silicon and manganese in metal decreased, in slag the contents of their oxides increased. The content of sulphur changed in a similar manner – it decreased in the metal and increased in the slag. An exception is carbon, the content of which always decreases compared to

the initial one, which is related to its oxidation with air oxygen or slag components [5].

Increase in temperature of slag ANF-6 to 1800 °C is accompanied by intensification of the processes of carbonisation and desulphurisation of metal (Table 4). Desulphurisation of metal increases with increase in temperature of slag AN-15M as well, but in this case the trend appears to increase in the degree of carbonisation of metal.

Therefore, in LMESS of die tools it is indicated to use flux AN-15M, which makes it possible to rapidly and uniformly melt the die surface, as well as keep the composition of the deposited metal practically unchanged compared to the initial metal of 5KhNM steel chips at a desulphurisation degree of up to 50 %.

1. Kuskov, Yu.M., Skorokhodov, V.N., Ryabtsev, I.A. et al. (2001) *Electroslag cladding*. Moscow: Nauka i Tekhnologii.
2. Voinov, S.G., Shalimov, A.G., Kosoj, L.F. et al. (1970) *Refining of steel by synthetic slags*. Moscow: Metallurgiya.
3. Ponomarev, A.G., Kozlov, Yu.E. (1974) About solubility of carbon in slags. *Izvestiya AN SSSR. Series Metallurgy*, **5**, 10–14.
4. Voronin, A.E., Latash, Yu.V., Nikolaev, V.A. et al. (1976) Investigation of carbonisation of metal in electroslag process with graphitized electrode. *Spets. Elektrometallurgiya*, Issue 32, 22–27.
5. Volkotrub, N.N., Lyuty, I.Yu., Voronin, A.E. et al. (1978) Specifics of the process of cast iron carbonisation in electroslag treatment. *Ibid.*, Issue 37, 24–30.
6. Biktagirov, F.K. (2003) Carbon behaviour in electroslag treatment of metals. In: *Proc. of 8th Int. Conf. on Problems of Welding, Metallurgy and Related Technologies* (Tbilisi, Oct. 2003), 255–265.
7. Medovar, B.I., Tsykulenko, A.K., Shevtsov, V.L. et al. (1986) *Electroslag process metallurgy*. Kiev: Naukova Dumka.
8. Makara, A.M., Mosendz, N.A. (1971) *Welding of high-strength steels*. Kiev: Tekhnika.
9. Latash, Yu.V., Fetisova, T.Ya., Voronin, A.E. (1985) Study of electrical conductivity and viscosity of slags (fluxes) of $\text{CaF}_2\text{-CaO-Al}_2\text{O}_3\text{-SiO}_2$ system applied in electroslag technology: Report 3. *Spets. Elektrometallurgiya*, Issue 58, 11–17.