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Effect of Additives Introduction to Fluxes Manufactured from Ladle Electric Steel Slag

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Abstract—Studies of welding and surfacing fluxes containing ladle slag of electric steel production of rail steel of EVRAZ ZSMK JSC were carried out. Welding under the flux was performed on the samples of sheet steel 09G2S by Sv-08GA wire using the welding tractor ASAW1250 at exhaust modes. Chemical compositions of welding fluxes and slag crusts were determined. Also, chemical composition of the studied welded samples was determined according to GOST 10543–98 by X-ray fluorescence method on XRF-1800 spectrometer and by atomic emission method on DFS-71 spectrometer. Metallographic studies were carried out with the use of an OLYMPUS GX-51 optical microscope. The content of total oxygen and surface oxygen was studied using the LECO TC–600 analyzer. The possibility of using technogenic waste products of metallurgical production is shown for the production of welding fluxes. The following components were used for production of welding flux: ladle slag of electric steelmaking of rail steel from EVRAZ ZSMK JSC; BSK barium-strontium modifier produced under the terms of 1717-001-75073896–2005 by NPK Metallotekhnoprom; slag of silicomanganese production from West Siberian steel plant; electro static dust of aluminum production from RUSAL (carbonfluor-containing supplement). The studies have shown the suitability of the use of ladle electric steel slag for welding and surfacing of alloyed metal. The introduction of various flux additives reduces the concentration of total oxygen in the weld metal, which in turn increases the toughness. From the point of oxygen concentration in weld metal and impact toughness, it is better to use silica-manganese slag and carbon-fluoride additive as flux additives.

Keywords: welding, surfacing, welding fluxes, industrial waste, ladle furnace slag, toughness, total oxygen

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INTRODUCTION

Contamination of welds and deposited metal with non-metallic inclusions is predetermined, ceteris paribus, by the viscosity and oxidation of the slag system. Moreover, the mechanical properties of the weld are predetermined by the presence of nonmetallic inclusions of both endogenous and exogenous types [1, 2].

To reduce the cost of production and manufacturing of welding and surfacing materials, as well as to reduce the level of pollution from non-metallic inclusions, lighter-melting slag systems have recently been used, including those with the use of technogenic waste from metallurgical production, [3–18].

Previously, various compositions of welding fluxes using ladle electric steel slag were studied in [19–21]: the chemical composition of the samples was studied, wear tests were carried out, and the quantitative composition of non-metallic inclusions was investigated.

The objective of this work is to conduct studies of the dependence of the mechanical properties of the weld on oxygen concentration.

RESEARCH METHODS

The chemical composition of the studied welded samples was determined according to GOST 10543–98 by the X-ray fluorescence method on the XRF-1800 spectrometer and the atomic emission method on the DFS-71 spectrometer. Metallographic studies were carried out according to GOST 1778–70 on microsections without etching using an OLYMPUS GX-51 optical microscope at a magnification of 100. Fractional gas analysis was performed using a LECO TS-600 analyzer. The study of welded samples for impact strength

Table 1. Composition of welding fluxes

Sample	Content in the welding flux, %			
	ladle slag	silica-manganese slag	barium-strontium modifier	carbon-fluorine additive
1	100	–	–	–
2	94	–	6	–
3	20	80	–	–
4	44	50	–	6
5	94	–	–	6

Table 2. Chemical composition of the studied fluxes

Flux	Mass fraction of elements, %													
	FeO	MnO	CaO	SiO_2	Al_2O_3	MgO	Na_2O	K_2O	S	P	ZnO	Cr_2O_3	F	TiO_2
1	0.50	7.97	31.34	46.09	6.61	5.74	1.40	0.010	0.33	0.011	0.004	0.050	0.45	0.07
2	1.30	7.35	33.64	44.87	4.77	5.44	1.52	0.210	0.34	0.009	0.080	0.050	2.09	0.28
3	0.42	6.90	32.06	46.20	6.85	4.03	1.40	0.082	0.34	0.011	0.003	0.024	0.89	0.11
4	1.12	7.58	32.26	45.15	5.56	5.63	1.34	0.022	0.35	0.010	0.004	0.040	1.45	0.24
5	1.05	7.12	33.05	46.03	7.03	5.15	1.45	0.035	0.33	0.012	0.006	0.020	1.86	0.21

(KCV) at positive and negative temperatures was carried out using a pendulum hammer according to GOST 9454–78.

RESULTS AND COMPREHENSIVE REVIEW

In the present work, further studies of welding and surfacing fluxes containing ladle slag of electric steel production of rail steel of EVRAZ—West Siberian Smelter JSC (EVRAZ ZSMK JSC) were carried out. Based on the results of previous studies [19–21], the best samples of welding flux were selected to study the toughness and total oxygen content in the weld metal. For the manufacture of welding flux, components of the following chemical composition were used:

—ladle slag of electric steel production of rail steel of EVRAZ ZSMK JSC, % (by weight): 1.31 FeO, 0.22 MnO, 36.19 CaO, 36.26 SiO_2, 6.17 Al_2O_3, 11.30 MgO, 0.28 Na_2O, 0 K_2O, 3.34 F, <0.12 C, 1.26 S, 0.02 P;

—barium-strontium modifier BSK according to TU 1717-001-75073896 – 2005 manufactured by NPK Metallotekhnoprom LLC, % (by weight): 13.0–19.0 BaO, 3.5–7.5 SrO, 17.5–25.5 CaO, 19.8–29.8 SiO_2, 0.7–1.1 MgO, 2.5–3.5 K_2O, 1.0–2.0 Na_2O, 1.5–6.5 Fe_2O_3, 0–0.4 MnO, 1.9–3.9 Al_2O_3, 0.7–1.1 TiO_2, 16.0–20.0 CO_2;

—silicomanganese slag produced by the West Siberian steel plant, % (by weight): 6.91–9.62 Al_2O_3, 22.85–31.70 CaO, 46.46–48.16 SiO_2, 0.27–0.81 FeO, 6.48–7.92 MgO, 8.01–8.43 MnO, 0.28–0.76 F, 0.26–0.36 Na_2O, up to 0.62 K_2O, 0.15–0.17 S, 0.01 P;

—dust of electrofilters of aluminum production of OK RUSAL (carbon-containing additive), % (by weight): 21.00–46.23 Al_2O_3, 18–27 F, 8–15 Na_2O, 0.4–6.0 K_2O, 0.7–2.3 CaO, 0.50–2.48 SiO_2, 2.10–3.27 Fe_2O_3, 12.5–30.2 C_{tot}, 0.07–0.90 MnO, 0.06–0.90 MgO, 0.09–0.19 S, 0.10–0.18 P.

The composition of welding fluxes is presented in Table 1.

The manufacturing scheme of welding flux and flux additives is described in earlier studies [19–21]. Welding under fluxes was carried out end-to-end without beveling edges on both sides on samples of size 500 × 75 mm, thickness 16 mm, made of sheet steel of 09G2S grade. The process was carried out by the Sv-08GA wire with diameter of 4 mm using the ASAW1250 welding tractor. Welding mode: current strength (I_{sv}) 680 A, voltage (U_d) 28 V, welding speed (V_{sv}) 28 m/h.

After welding the samples, the chemical compositions of welding fluxes (Table 2), slag crusts (Table 3), and welded samples (Table 4) were determined.

Table 3. Chemical composition of slag crusts

Flux	Mass fraction of elements, %													
	FeO	MnO	CaO	SiO_2	Al_2O_3	MgO	Na_2O	K_2O	S	P	ZnO	Cr_2O_3	F	TiO_2
1	1.69	7.78	32.35	42.50	6.59	5.55	0.30	0.01	0.21	0.011	0.012	0.04	0.37	0.07
2	4.44	6.53	33.61	39.46	4.47	6.89	4.32	0.22	0.555	0.023	0.007	0.007	2.37	0.30
3	1.78	6.36	33.10	43.13	7.23	4.38	1.19	0.088	0.23	0.012	0.004	0.034	0.83	0.12
4	1.86	6.87	33.25	42.56	5.74	5.26	2.13	0.046	0.28	0.014	0.006	0.024	2.55	0.18
5	1.74	6.56	33.51	41.78	6.38	5.44	1.86	0.074	0.41	0.018	0.007	0.014	2.68	0.15

Table 4. Chemical composition of welded samples

Flux	Mass fraction of elements, %									
	C	Si	Mn	Cr	Ni	Cu	V	Mo	S	P
1	0.10	0.43	1.16	0.05	0.11	0.14	0.007	0.021	0.019	0.012
2	0.10	0.18	0.50	0.05	0.14	0.15	0.006	0.017	0.046	0.013
3	0.04	0.41	1.22	0.04	0.09	0.13	0.001	0.010	0.031	0.010
4	0.08	0.42	1.22	0.03	0.07	0.14	0.001	0.010	0.031	0.009
5	0.12	0.18	0.72	0.02	0.10	0.17	0.002	0.013	0.027	0.008

Samples were cut from welded samples to study non-metallic inclusions, to determine the oxygen content in the weld metal and to determine the impact strength (KCV) at positive and negative temperatures. Metallographic studies were performed using the OLYMPUS GX-51 optical microscope on microsections without etching at a magnification of 100 (Fig. 1).

Assessment of non-metallic inclusions was carried out according to GOST 1778–70, with results shown in Table 5. Studies of the total oxygen and surface oxy-

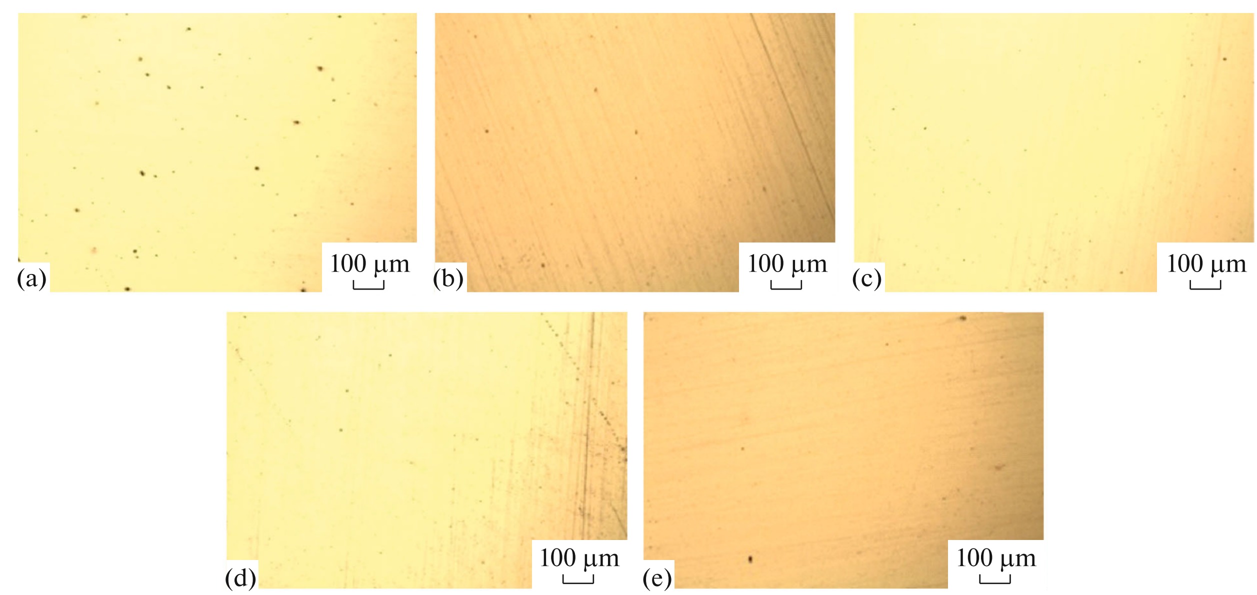

Fig. 1. Non-metallic inclusions in zone of welded samples *1*–*5* (a–e).

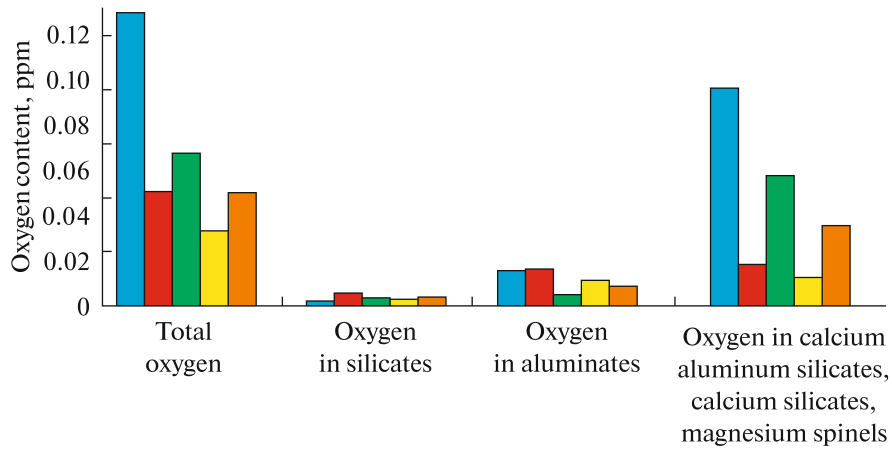

Fig. 2. Oxygen content in welds: ■—*1*; ■—*2*; ■—*3*; ■—*4*; ■—*5*.

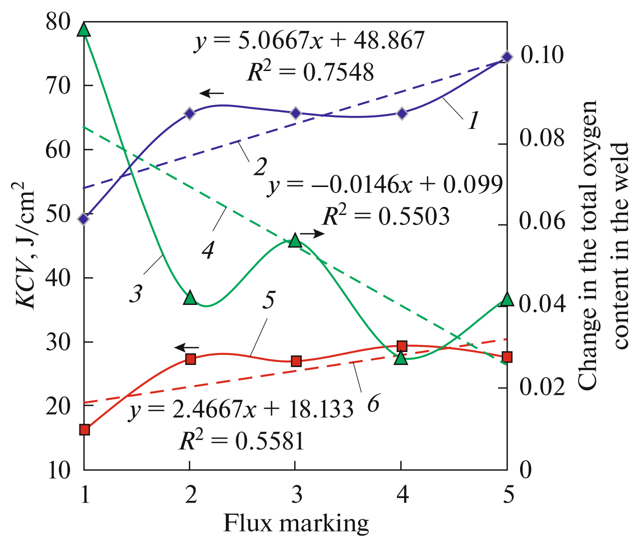

Fig. 3. Change in toughness and total oxygen content in a weld: (*1* and *2*) change and linear change in impact strength (*KCV*) at $t = 20°$ C; (*3* and *4*) change and linear change in the content of total oxygen; (*5* and *6*) change and linear change in impact strength (*KCV*) at $t = -20°$ C.

gen content were carried out using the LECO TC–600 analyzer (Table 6, Fig. 2).

With the introduction of various flux additives in the ladle electric steel slag, the oxygen concentration in the welds decreases.

The results of studies of impact strength (KCV) at positive and negative temperatures are presented below and in Fig. 3.

Sample	Impact strength, J/cm² $KCV^{+20°C}$	Impact strength, J/cm² $KCV^{-20°C}$
0	49.0	16.3
1	65.7	27.3
2	65.7	27.0
3	65.7	29.3
4	74.3	27.7

In the study of the toughness of welded samples, it was found that with the use of various flux additives, toughness increases at positive and negative temperatures.

Table 5. Non-metallic inclusions in the welds' metal

Flux	Non-metallic inclusions, points	
	non-deformable silicates	one-dimensional oxides
1	1b, 2b, 3b	3a
2	1b, 2b	2a
3	1b, 2b	2a
4	1b, rarely 2b	1a
5	1b, 2b	1a

Table 6. Content of oxygen and compounds in welds

Sample	Content, %			
	total and surface oxygen	silicates	aluminates	calcium aluminum silicates, calcium silicates, magnesium spinels
1	0.10785	0.00122	0.12595	0.08074
2	0.04205	0.0042	0.01347	0.015135
3	0.0561	0.00294	0.003595	0.04803
4	0.0276	0.00205	0.009135	0.010175
5	0.042	0.00303	0.007175	0.029505

CONCLUSIONS

Studies conducted have shown the suitability of using ladle electric steel slag for welding and surfacing of alloyed metal. Moreover, the introduction of various flux additives reduces the concentration of total oxygen in the welds, which, in turn, increases the toughness at positive and negative temperatures. It has been determined that the best, from the point of view of oxygen concentration in the weld metal and impact strength, is the use of silica-manganese slag and a carbon-fluorine additive as flux additives.

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