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ARTICLE

Production of new welding fluxes based on silicomanganese slag

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ABSTRACT

The properties of a welding flux based on the silicomanganese slag are investigated. The flux is produced using the slag formed in the production of silicomanganese with different ratios of the slag fractions and different content of the water glass in the flux addition. The addition of up to 20–30% dust fraction of the silicomanganese slag to the composition of the flux results in excellent mechanical properties of specimens taken from the welded plates. The FD-UFS addition reduces the extent of contamination with non-metallic inclusions and reduces the size and amount of these inclusions. The optimum content of the water glass in the flux (up to 20–30%) was determined. Consequently, the resultant mechanical properties of the specimens taken from the welded plates are very high.

KEYWORDS

welding; fluxes; technology; welding joint; samples; nonmetallic inclusions; microstructure; grain size; mechanical properties

The development, investigation and production of new welding fluxes is the subject of extensive research both in the Russian Federation and abroad [1–18]. It has been proposed to use the slag produced in the production of silicomanganese for preparing welding fluxes [19,20], and the technology is protected by patents. In this work, attention is given to the possibilities of efficient application of the silicomanganese slag for the production of welding fluxes.

The flux was produced using the slag formed in the production of silicomanganese with the chemical composition presented in Table 1. In the first series of the experiments, the possibility of formation of different ratios of the slag fractions was investigated. The fraction and component compositions of the investigated fluxes are presented in Table 2. Welding under a flux was carried out by butt welding without edge preparation on two sides on specimens with the size of 500 × 75 mm, thickness 16 mm, made of 09G2S steel sheets. Welding was carried out using Sv-08GA wire and an ASAW-1250 welding tractor in the conditions: I_w = 700 A, U_a = 30 V; V_w = 35 m/h.

Specimens were cut out from the welded plates and subjected to x-ray diffraction analysis of the composition of the weld metal and metallographic studies of the metal of the welded joints. The chemical composition of the welding fluxes is presented in Table 3. The chemical composition of the slag skin is listed in Table 4, and the chemical composition of the metal of the welded joints is given in Table 5.

Metallographic studies were carried out on microsections without etching using an Olympus GX-51 optical microscope, magnification ×100. The results of analysis of the presence of the non-metallic inclusions in the zone of the welded joint, carried out according to the GOST 1778–70 standard, are shown in Figure 1 and Table 5.

The metallographic studies of the structure of the metal in the zone of the welded joints were conducted in the Olympus GX-51 optical microscope in the bright field at a magnification of 500 after etching the surface of the specimens in a 4% nitric acid solution. The grain size was determined in accordance with the GOST 5639–82 standard. The microstructure of the metal of the welded joint is shown in Figure 2.

Specimens were taken from the welded plates and their mechanical properties determined. The mechanical tests of the specimens, taken from the welded plates, yielded the results indicating the increase of impact toughness values (Figure 3).

Analysis of the results of the determination of the mechanical properties of the specimens, taken from the welded sheets, shows that the optimum content of the dust fraction smaller than 0.45 mm in the flux is 20–30%. At this content of the dust fraction smaller than 0.45 mm the flux is characterized by the favourable mechanical properties of the specimens taken from the welded plates.

Ferrite is present in the structure of the weld metal of all testpieces in the form of non-equiaxed grains, stretched in the direction of heat removal. There is a distinctive transition from the uniform ferritic–pearlitic structure to the structure of pearlite and ferrite of the Widmanstaetten direction. The specimens did not show any large changes in the grain size on the grain size scale (Tables 6 and 7).

In the second series of the tests, attention was given to the possibilities of using a ceramic flux produced from the dust of silicomanganese slag with the fraction of up to 0.45 mm bonded with water glass. The flux was prepared by mixing the silicomanganese slag with water glass at different ratios (Table 2), followed by drying, crushing, screening and formation of the 0.45–2.5 mm fraction.

Table 1.

Content, %										
Al_2O_3	CaO	SiO_2	FeO	MgO	MnO	F	Na_2O	K_2O	S	P
6.91–9.62	22.85–31.70	46.46–48.16	0.27–0.81	6.48–7.92	8.01–8.43	0.28–0.76	0.26–0.36	Up to 0.62	0.15–0.17	0.01

Table 2.

Specimen	Content, % of fraction, mm
1	100 % fraction 0.45 — 2.5
2	95 % fraction 0.45 — 2.5 + 5 % fraction <0.45
3	90 % fraction 0.45 — 2.5 + 10 % fraction < 0.45
4	85 % fraction 0.45 — 2.5 + 15 % fraction < 0.45
5	80 % fraction 0.45 — 2.5 + 20 % fraction < 0.45
6	70 % fraction 0.45 — 2.5 + 30 % fraction < 0.45
7	60 % fraction 0.45 — 2.5 + 40 % fraction < 0.45
8	60 % silicomanganese slag + 40 % water glass
9	70 % silicomanganese slag + 30 % water glass
10	80 % silicomanganese slag + 20 % water glass
11	85 % silicomanganese slag + 15 % water glass

The non-metallic inclusions in the zone of the welded joints are presented in Table 6. The grain size of the welded joints, determined with accordance with the GOST 5639–82 test, is presented in Table 7.

Analysis of the results of the mechanical tests of the specimens taken from the welded plates was used to determined the optimum content of water glass in the flux (up to 20–30%) for obtaining the favourable mechanical properties of the specimens taken from the welded plates (Figures 4 and 5).

However, the produced fluxes are oxidized and formed by the silicon – manganese–oxidation–reduction processes and, consequently, the products of these reactions are the oxide compounds of silicon and manganese thus increasing the degree of contamination of the metal of the welded

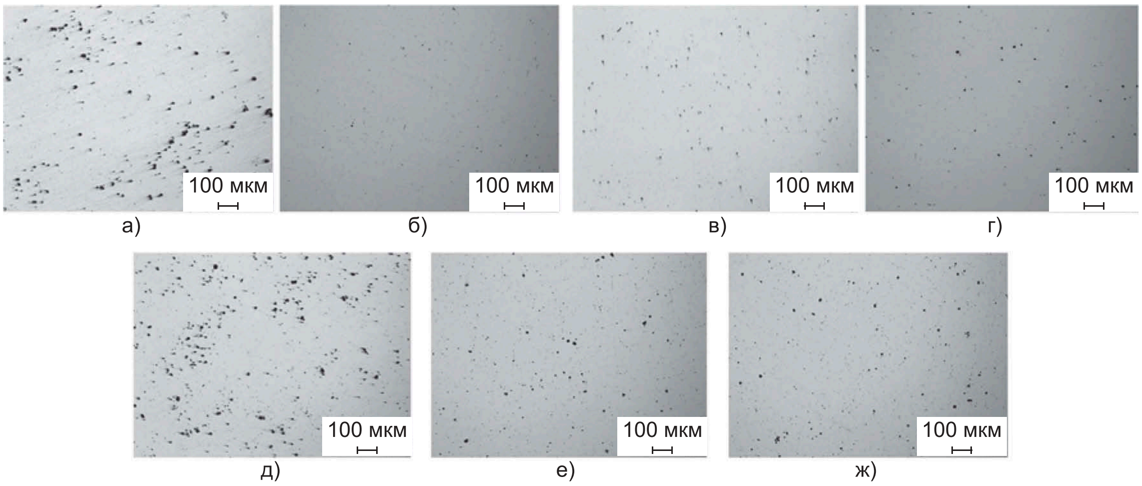

Figure 1. Non-metallic inclusions in the weld zone of the specimens: a – 1; b – 2; c – 3; d – 5; f – 6; g – 7. mkm = μm.

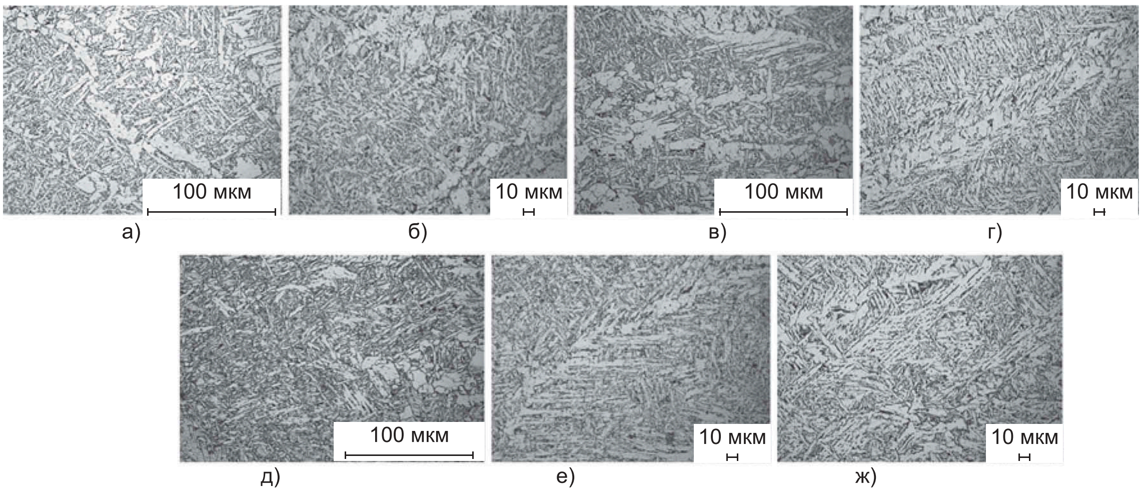

Figure 2. Microstructures of the welded joints in the specimens: a – 1; b – 2; c – 3; d – 5; f – 6; g – 7. mkm = μm.

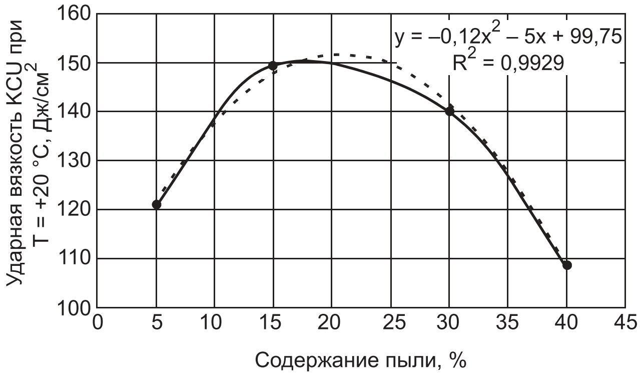

Figure 3. Effect of the content of the dust fraction (smaller than 0.45 mm) in the flux on impact toughness. Содержание пыли, % = Dust content, %; Ударная вязкость KCU при T = +20°C, Дж/см^2 = Impact toughness KCU at T = +20°C, J/cm^2.

Table 3.

Specimen	Content, %									
	Al_2O_3	CaO	SiO_2	FeO	MgO	MnO	F	Na_2O	S	P
8	5.29	25.84	51.75	0.55	5.02	7.39	0.36	4.66	0.12	0.01
9	5.48	26.68	51.73	0.57	5.16	7.59	0.39	4.19	0.13	0.01
10	5.88	25.53	52.53	0.56	5.07	7.75	0.31	4.07	0.13	0.01
11	6.55	26.81	51.14	0.56	5.78	8.10	0.35	2.62	0.14	0.01

Table 4.

Specimen	Content, %										
	MnO	SiO_2	CaO	MgO	Al_2O_3	FeO	Na_2O	K_2O	F	S	P
1	7.90	46.04	23.38	6.77	10.08	2.07	0.37	0.65	0.73	0.13	0.01
2	7.87	45.58	31.82	6.62	6.77	1.35	0.26	None	0.32	0.11	0.01
3	7.83	44.54	23.84	6.43	9.64	3.59	0.37	0.65	0.69	0.12	0.008
4	8.09	45.91	31.15	6.60	6.79	1.39	0.27	None	0.29	0.11	0.01
5	7.93	45.67	23.84	6.54	9.87	2.86	0.37	0.65	0.72	0.12	0.008
6	8.16	45.74	29.39	6.22	6.93	1.99	0.26	None	0.36	0.12	0.01
7	8.23	45.52	29.12	6.29	6.65	1.88	0.28	None	0.26	0.12	0.01
8	8.19	48.79	24.42	4.82	5.14	2.45	3.64	None	0.35	0.09	0.01
9	8.29	49.92	26.12	5.37	5.60	2.64	3.25	None	0.37	0.10	0.01
10	8.16	48.25	26.32	5.22	6.02	2.17	3.12	None	0.33	0.12	0.01
11	8.16	48.09	27.24	5.67	6.36	1.97	1.64	None	0.34	0.12	0.01

joint with the non-metallic inclusions and, consequently, reducing the physical and mechanical properties, especially at low subzero temperatures. To reduce the extent of contamination of the weld metal and improve the mechanical properties, experiments were carried out with the addition of FD-UFS flux to the new flux.

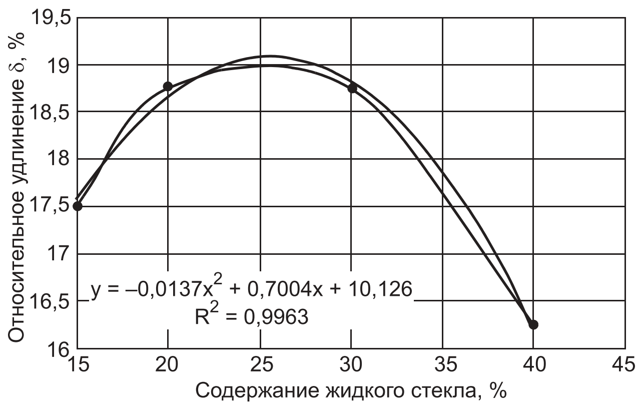

Figure 4. Effect of the water glass content in the flux on relative elongation. Содержание жидкого стекла, % = Water glass content, %; Относительное удлинение δ, % = Relative elongation δ, %.

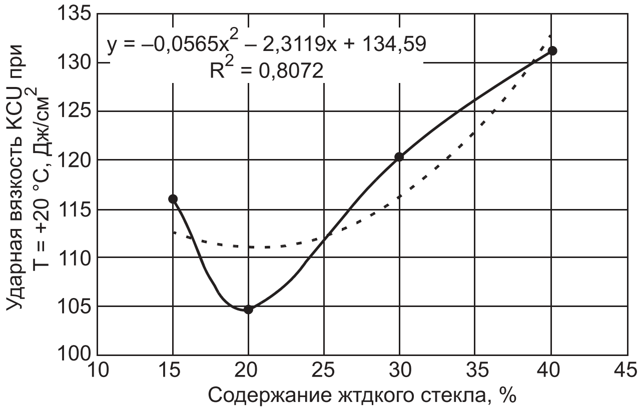

Figure 5. Effect of the water glass content in the flux on impact toughness. жидкого стекла, % = Water glass content, %; Ударная вязкость KCU при T = +20°C, Дж/см^2 = Impact toughness KCU at T = + 20°C, J/cm^2.

Table 5.

	Content, %										
Specimen	C	Si	Mn	Cr	Ni	Cu	V	Nb	Al	S	P
1	0.09	0.71	0.51	0.03	0.10	0.11	0.001	0.014	0.023	0.018	0.012
2	0.08	0.54	1.33	0.04	0.05	0.08	0.003	0.014	0.015	0.008	0.008
3	0.09	0.61	1.49	0.04	0.11	0.11	0.01	0.013	0.018	0.016	0.010
4	0.07	0.45	1.24	0.02	0.05	0.07	0.002	0.014	0.014	0.006	0.007
5	0.08	0.66	1.42	0.03	0.10	0.11	0.002	0.015	0.023	0.018	0.012
6	0.08	0.61	1.42	0.02	0.06	0.08	0.003	0.014	0.029	0.010	0.011
7	0.08	0.59	1.39	0.02	0.02	0.05	0.004	0.018	0.091	0.014	0.009
8	0.05	0.52	1.25	0.02	0.04	0.05	0.003	0.017	0.020	0.005	0.007
9	0.03	0.51	1.23	0.02	0.04	0.06	0.002	0.017	0.017	0.007	0.008
10	0.06	0.53	1.31	0.02	0.04	0.06	0.004	0.016	0.018	0.012	0.009
11	0.09	0.52	1.31	0.02	0.04	0.06	0.003	0.015	0.013	0.010	0.008

Table 6.

	Non-metallic inclusions, size number		
Specimen	Silicates not deformed	Brittle silicates	Point oxides
1	4b; 3b; 4a	3b	1
2	2b; 1b; 3a; 4a	none	1a; 2a
3	4b; 2b	none	1a; 2a
4	2b; 4b	none	1a; 2a
5	4b; 5b; 3b	none	1a; 2a
6	2b; 1b; 2a; 2; 5a	none	1a; 2a
7	2b; 2a; 2; 5a	none	1a; 2a
8	2b; 1b; 2a; 2; 5a	none	1a
9	2b; 1b; 2a; 2; 5a	none	1a
10	2b; 1b; 2a; 2; 5a	none	1a; 2a
11	2b; 2; 5a	none	1a; 2a

Table 7.

Specimen	Grain size on the grain size scale
1	№ 4, № 5
2	№ 5, № 4
3	№ 4, № 5, № 6
4	№ 4
5	№ 5, № 4
6	№ 4
7	№ 4
8	№ 5, № 4
9	№ 4, № 5
10	№ 4
11	№ 4, № 5

The experiments were carried out using a flux-addition to the new flux mixed added in the ratios of 2, 4, 6 and 8%, respectively.

The chemical composition of the investigated slag skin is presented in Table 8, and the composition of various

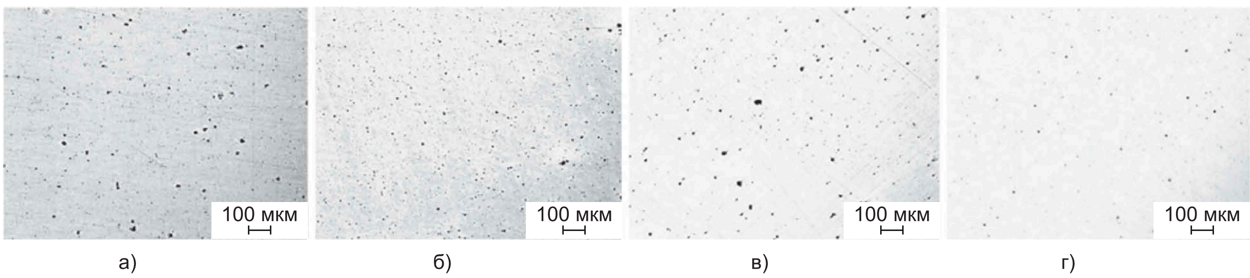

Figure 6. Non-metallic inclusions in the zone of the welded joint in the specimens with the addition, %: (a) 2; (b) 4; (c) 6; (d) 8. mkm = μm.

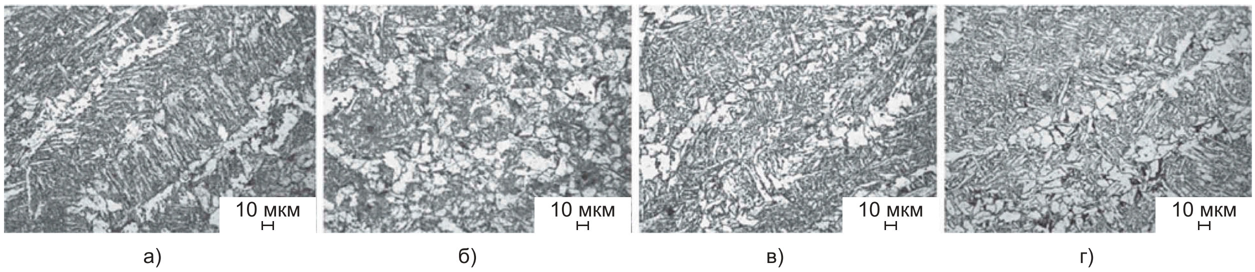

Figure 7. Microstructure of welded joints in specimens with the addition, %: (a) 2; (b) 4; (c) 6; (d) 8. mkm = μm.

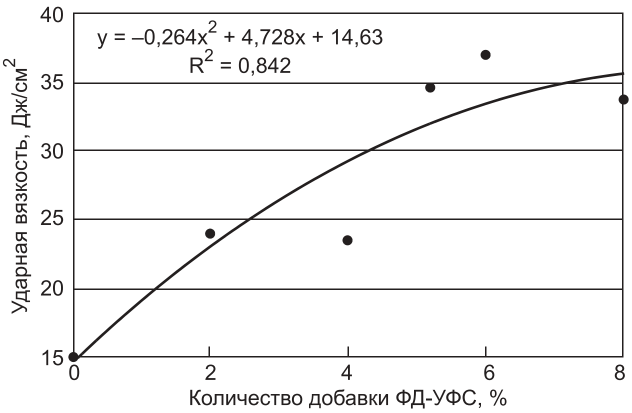

Figure 8. Effect of the content of the FD-UFS addition in the flux on impact toughness (KCV at – 20°C). Ударная вязкость, Дж/см^2 = Impact toughness, J/cm^2. Количество добавки ФД-УФС, % = Amount of FD-UFS addition, %.

Table 8.

FD-YFS content in flux, %	FeO	MnO	Ca	SiO_2	Al_2O_3	MgO	Na_2O	K_20	S	P	ZnO	F
2	0.40	8.01	15.80	50.08	11.55	7.39	0.77	0.63	0.22	0.008	0.002	1.30
4	0.91	7.90	17.72	46.63	10.32	6.63	1.10	0.68	0.01	0.01	None	1.95
6	0.81	7.68	16.79	43.64	11.27	5.71	2.25	0.65	0.01	0.01	0.003	4.04
8	0.46	7.46	16.00	43.64	11.86	5.56	2.30	0.60	0.01	0.01	0.002	3.96

Table 9.

FD-YFS content in flux, %	FeO	MnO	Ca	SiO_2	Al_2O_3	MgO	Na_2O	K_20	S	P	ZnO	F
2	2.21	7.25	15.55	38.09	9.39	8.63	0.49	0.57	0.12	0.006	0.002	0.94
4	2.28	7.39	16.90	42.00	9.76	5.77	0.76	0.62	0.15	0.008	0.002	1.12
6	2.24	7.20	16.06	39.94	11.15	7.14	1.09	0.60	0.17	0.008	0.002	1.53
8	2.36	7.14	14.70	42.87	12.40	5.57	1.34	0.57	0.20	0.008	0.002	1.88

Table 10.

	Mass fraction of elements, %									
FD-YFS content in flux, %	C	Si	Mn	Cr	Ni	Cu	Nb	Al	S	P
2	0.09	0.62	1.40	0.02	0.06	0.09	0.014	0.023	0.020	0.008
4	0.10	0.60	1.34	0.02	0.07	0.08	0.010	0.013	0.023	0.009
6	0.12	0.66	1.43	0.02	0.06	0.10	0.011	0.012	0.027	0.008
8	0.13	0.65	1.36	0.03	0.06	0.09	0.013	0.013	0.024	0.008

Table 11.

	Non-metallic inclusions, size number		
FD-YFS content in flux, %	Silicates not deformed	Brittle silicates	Point oxides
2	2b, 4b, 5a	none	1a, 2a
4	2b, 4b	none	1a, 2a
6	2b, 4b, 1b	none	1a, 2a
8	2b	none	1a, 2a

slag skins is in Table 9. The chemical composition of the metal of the welded joint is listed in Table 10.

The results of analysis of the presence of the non-metallic inclusions in the zone of the welded joint, carried out in accordance with the GOST 1778–70 procedure, are presented in Figure 6 and Table 11.

Consequently, the highest degree of contamination with the non-metallic inclusions was found in the metal of the welded joint produced under the flux without the addition. The FD-UFS addition reduces the degree of contamination with the non-metallic inclusions and also decreases their size and amount. In the investigated ranges, the level of contamination with the non-metallic inclusions is reduced more efficiently by the additions in the amount of 8%.

The microstructure of the welded joint of the specimens is presented in Figure 7. It can be seen that adding the additional flux in the amount up to 8% has no influence on the size and morphology of the structural components.

The results of determination of the mechanical properties show that the properties improve with the increase of the amount of the FD-UFS addition (Figure 8). The investigations form the basis for Russian Federation patents (RF Patent No. 2576717, 2016; RF Patent No. 257412, 2016).

Conclusions

(1) It is shown possible to use the slag obtained in the production of silicomanganese for the preparation of welding fluxes.
(2) Up to 30% of the fine fraction (smaller than 0.45 mm) can be used in the fluxes. At this content of the dust fraction in the flux the mechanical properties of the welded joints in the welded plates are high.
(3) The optimum content of the water glass in the flux, producing high mechanical properties, is (20–30%).
(4) It has been proposed that to reduce the degree of contamination of the metal of the welded joint with the oxide non-metallic inclusions and improve the mechanical properties of the welded joints, 2–8% of the FD-UFS flux should be added to the flux based on the silicomanganese slag. This addition reduces the level of contamination with the non-metallic inclusions and also their size and amount.

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