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Quality of Weld Seams Produced with Flux Based on Silicomanganese Slag

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Abstract—The use of metallurgical wastes in welding fluxes is considered. A new welding flux based on slag from silicomanganese production is proposed, along with the corresponding manufacturing technology. The quality of the weld seams is studied by metallographic analysis. The grain size and content of nonmetallic inclusions are determined. An Olympus GX-51 optical microscope is used for metallographic analysis (magnification ×100–1000). The influence of the fractional composition on the performance of the fluxes is studied. The optimal fraction is chosen, ensuring low content of nonmetallic inclusions (in particular, nondeforming silicates and oxides) in the weld seam. If 30–40% of the small fraction of welding flux is employed, the content of nonmetallic oxide inclusions in the weld seam is reduced. Metallographic analysis shows that introducing the small fraction has no effect on the structural components of the weld seam. The seam is characterized by ferrite–pearlite structure. The ferrite is present in the form of grains extended in the direction of heat transfer. The optimal content of the <0.45 mm fraction in the welding flux is 30–40%. To improve flux performance, the small fraction may be mixed with liquid glass. The use of ceramic flux produced from the dust of silicomanganese slag (<0.45 mm fraction) bound by liquid glass reduces the content of nonmetallic inclusions in the weld seam. However, increase in the content of liquid glass from 15 to 40% has little effect on the content of nonmetallic oxide inclusions in the weld seam or on the microstructure. The microstructure in the weld seam consists of pearlite and ferrite. The optimal flux consists of the small fraction with 15–20% liquid glass.

Keywords: welding, flux, metal quality, silicomanganese slag, chemical composition, microstructure, grain size, nonmetallic inclusions, weld seam

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The creation of new welding fluxes is of great interest in Russia and elsewhere [1–18]. In the present work, we propose the use of slag from silicomanganese production in the manufacture of welding fluxes [17, 20]. This technology has been patented [21, 22].

The composition of the slag from silicomanganese production is as follows:

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.

We consider two series of experiments. In the first, the use of slags with different fractional composition is investigated:

Sample	Fractional composition
	First series of experiments
1	100% 0.45–2.5 mm fraction
2	95% % 0.45–2.5 mm fraction + 5% <0.45 mm fraction
3	90% % 0.45–2.5 mm fraction + 10% <0.45 mm fraction
4	85% % 0.45–2.5 mm fraction + 15% <0.45 mm fraction
5	80% % 0.45–2.5 mm fraction + 20% <0.45 mm fraction
6	70% % 0.45–2.5 mm fraction + 30% <0.45 mm fraction
7	60% % 0.45–2.5 mm fraction + 40% <0.45 mm fraction

Table 1. Chemical composition of slag crust

Sample	Content, %										
	MnO	SiO_2	CaO	MgO	Al_2O_3	FeO	Na_2O	K_2O	F	S	P
First series of experiments											
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	@отс.	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	@отс.	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	@отс.	0.36	0.12	0.01
7	8.23	45.52	29.12	6.29	6.65	1.88	0.28	@отс.	0.26	0.12	0.01
Second series of experiments											
8	8.19	48.79	24.42	4.82	5.14	2.45	3.64	0.35	0.09	0.01	–
9	8.29	49.92	26.12	5.37	5.60	2.64	3.25	0.37	0.10	0.01	–
10	8.16	48.25	26.32	5.22	6.02	2.17	2.12	0.33	0.12	0.01	–
11	8.18	48.09	27.24	5.67	6.36	1.97	1.64	0.34	0.12	0.01	–

Table 2. Chemical composition of weld seam

Sample	Content, %										
	C	Si	Mn	Cr	Ni	Cu	V	Nb	Al	S	P
First series of experiments											
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
Second series of experiments											
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

In the second series of experiments, we consider the use of ceramic flux with different proportions of the silicomanganese slag and liquid glass:

Sample	Fractional composition
Second series of experiments	
8	60% silicomanganese slag + 40% liquid glass
9	70% silicomanganese slag + 30% liquid glass
10	80% silicomanganese slag + 20% liquid glass
11	85% silicomanganese slag + 15% liquid glass

We investigate the butt welding of 500 × 75 mm 09G2S sheet steel samples (thickness 16 mm), without bending of the edges, on two sides. We use Sv-08GA welding wire and an ASAW-1250 welding system: I_{we} = 700 A; U_{arc} = 30 V; V_{we} = 35 m/h.

Samples cut from the welded plates are subjected to X-ray spectral analysis and metallographic investigation of the weld seam. Table 1 presents the chemical composition of the slag crust, while Table 2 presents the composition of the weld seam.

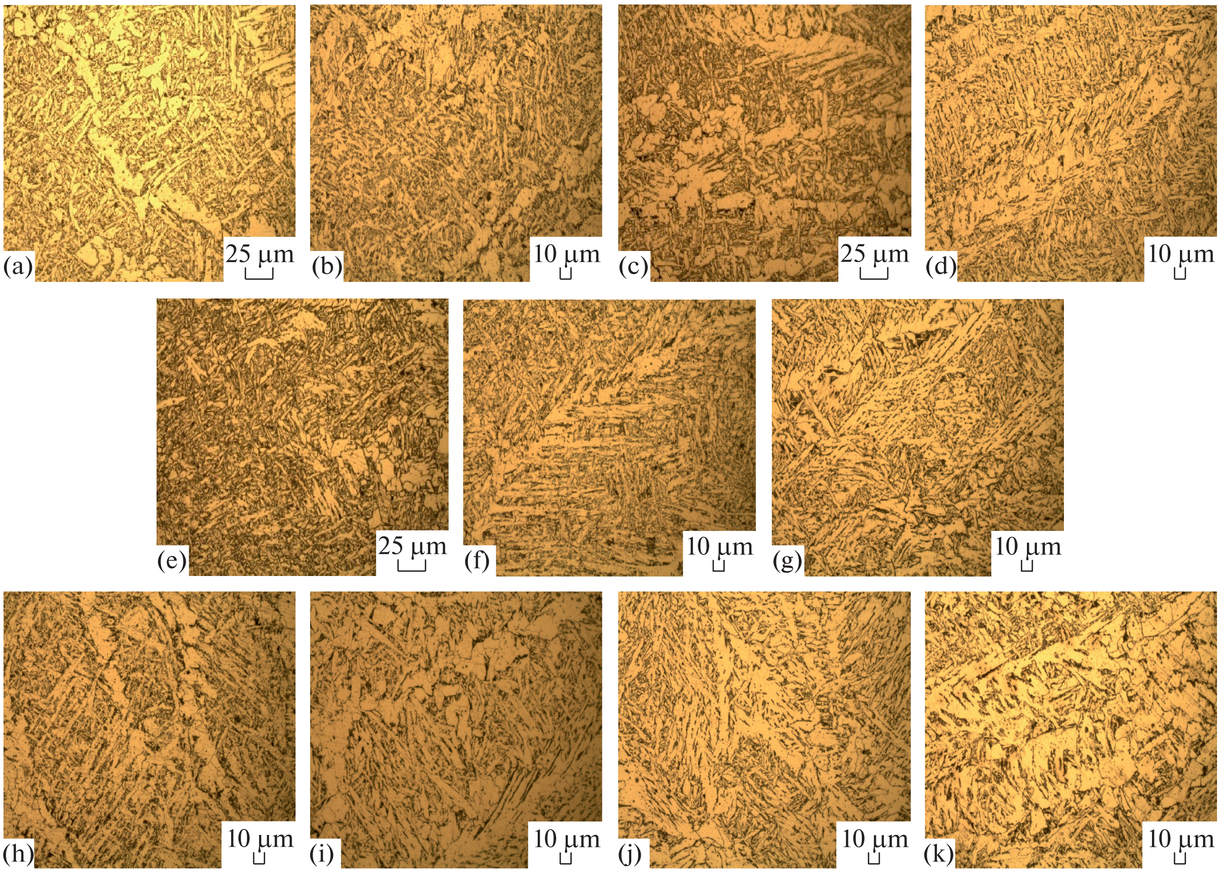

Fig. 1. Nonmetallic oxide inclusions in the weld seam of samples *1–11* (a–k, respectively).

An Olympus GX-51 optical microscope is used for metallographic analysis (magnification ×100). In Figs. 1a–1g, we show the data regarding nonmetallic inclusions in the weld seam (determined in accordance with State Standard GOST 1778–70). We also obtain the following results:

Sample	Nondeforming silicates, size score	Point oxides, size score
	First series of experiments	
1	4b; 3b; 4a	1a
2	2b; 1b; 3a; 4a	1a; 2a
3	4b; 2b	1a; 2a
4	2b; 4b	1a; 2a
5	4b; 5b; 3b	1a; 2a
6	2b; 1b; 2a; 2.5a	1a; 2a
7	2b; 2a; 2.5a	1a; 2a
	Second series of experiments	
8	2b; 1b; 2a; 2.5a	1a
9	2b; 1b; 2a; 2.5a	1a
10	2b; 1b; 2a; 2.5a	1a; 2a
11	2b; 2.5a	1a; 2a

Note that brittle silicates are only present in sample *1* (score 3b).

Analysis shows that increasing the content of the small fraction to 30% does not much change the content of nonmetallic oxide inclusions in the weld seam. However, in the range 30–40%, the content of nondeforming silicates in the weld seam declines.

The structure of the metal near the weld seam is studied metallographically by means of an Olympus GX-51 optical microscope in a light field (magnification ×100–1000), after surface etching in 4% nitric-acid solution. The grain size is determined in accordance with State Standard GOST 5639–82. In Fig. 2, we show the microstructure of the weld seam (at ×500 magnification).

For samples *1–7*, ferrite is present at the weld seam in the form of grains extended in the direction of heat transfer. We note a transition from uniform ferrite–pearlite structure to a Widmanstatten structure with pearlite and ferrite. No particle change in grain size is observed (in terms of the scale in State Standard GOST 5639–82:

Sample	Grain size
First series of experiments	
1	4, 5
2	5, 4
3	4, 5, 6

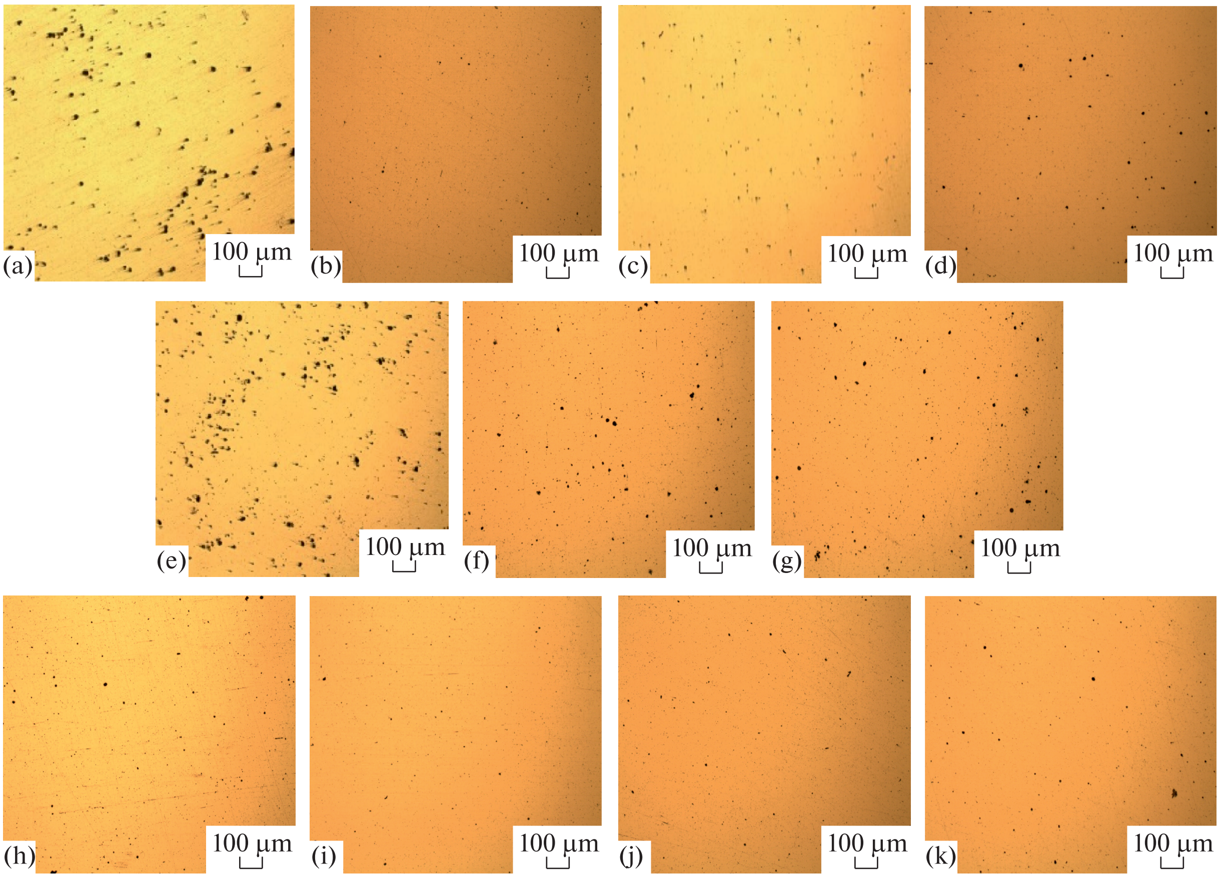

Fig. 2. Microstructure in the weld seam of samples *1*–*11* (a–k, respectively).

4	4
5	5, 4
6	4
7	4
Second series of experiments	
8	5, 4
9	4, 5
10	4
11	4, 5

In the second series of experiments (samples *8*–*11*), we study the possibility of welding with ceramic flux produced from dust consisting of silicomanganese slag (>0.45 mm slag), with liquid glass as the binder. This flux is produced by mixing the silicomanganese slag with liquid glass in different proportions (presented earlier), drying, crushing, and screening to obtain the 0.45–2.5 mm fraction.

Table 3 presents the chemical composition of welding fluxes *8*–*11*. Tables 1 and 2 present the corresponding composition of the slag crust and weld seam.

The content of nonmetallic oxide inclusions in the weld seam (determined in accordance with State Standard GOST 1778–70) for samples *8*–*11* is shown in Figs. 1h–1k and in Table 3. Analysis indicates that introducing liquid glass in the small silicomanganese fraction lowers the content of nonmetallic inclusions in the weld seam. However, further increase in the content of liquid glass from 15 to 40% has little effect

Table 3. Chemical composition of welding fluxes

Sample	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

on the content of nonmetallic oxide inclusions in the weld seam or on the microstructure.

The microstructure in the weld seam of samples *8–11* is shown in Figs. 2h–2k. We note a Widmanstatten structure with pearlite and ferrite. Little change in grain size is seen, as is evident from the data presented earlier.

CONCLUSIONS

In principle, the small fraction of silicomanganese slag may be used in the production of welding fluxes. Metallographic analysis shows that the content of nonmetallic oxide inclusions in the weld seam is reduced if 30–40% of the small fraction of welding flux is employed. This has no effect on the structural components of the weld seam. The optimal content of the <0.45 mm fraction in the welding flux is 30–40%.

To improve flux performance, the small fraction may be mixed with liquid glass. The introduction of liquid glass reduces the content of nonmetallic inclusions in the weld seam. However, increase in the content of liquid glass from 15 to 40% has little effect on the content of nonmetallic oxide inclusions in the weld seam or on the microstructure. The optimal flux consists of the small fraction with 15–20% liquid glass.

REFERENCES

1. Puchol, R.Q., Blanco, J.R., González, L.P., Hernández, G.C., and Gómez Pérez, C.R., The influence of the air occluded in the deposition layer of flux during automatic welding: a technological aspect to consider in the quality of the bead, *Weld. Int.*, 2009, vol. 23, no. 2, pp. 132–140.
2. Crespo, A.C., Puchol, R.Q., González, L.P., Sanchez, L.G., Gómez Pérez, C.R., Cedre, E.D., Mendez, T.O., and Pozol, J.A., Obtaining a submerged arc welding flux of the $MnO–SiO_2–CaO–Al_2O_3–CaF_2$ system by fusion, *Weld. Int.*, 2007, vol. 21, no. 7, pp. 502–511.
3. Crespo, A.C., Puchol, R.Q., González, L.P., Gómez Pérez, C.R., Castellanos, G., Díaz Cedré, E., and Ortíz, T., Study of the relationship between the composition of a fused flux and its structure and properties, *Weld. Int.*, 2009, vol. 23, no. 2, pp. 120–131.
4. Golovko, V.V. and Potapov, N.N., Special features of agglomerated (ceramic) fluxes in welding, *Weld. Int.*, 2011, vol. 25, no. 11, pp. 889–893.
5. Volobuev, Yu.S., Volobuev, O.S., Parkhomenko, A.G., Dobrozhela, E.I., and Klimenchuk, O.S., Using a new general-purpose ceramic flux SFM-101 in welding of beams, *Weld. Int.*, 2012, vol. 26, no. 8, pp. 649–653.
6. Volobuev, Yu.S., Surkov, A.V., Volobuev, O.S., Kipiani, P.N., Shestov, D.V., Pavlov, N.V., and Savchenko, A.I., The development and properties of a new ceramic flux used for reconditioning rolling stock components, *Weld. Int.*, 2010, vol. 24, no. 4, pp. 298–300.
7. Potapov, N.N. and Kurlanov, S.A., A criterion for evaluating the activity of fused welding fluxes, *Weld. Int.*, 1987, vol. 1, no. 10, pp. 951–954.
8. Babushkin, P.L. and Persits, V.Yu., Determination of hydrogen in the form of moisture in basic electrode coatings and fluxing materials in metallurgical production, *Weld. Int.*, 1991, vol. 5, no. 9, pp. 741–742.
9. Pavlov, I.V. and Oleinichenko, K.A., Regulating generation of CO by varying the composition of ceramic fluxes, *Weld. Int.*, 1995, vol. 9, no. 4, pp. 329–332.
10. Chigarev, V.V. and Kosenko, A.A., Regulating the silicon-reduction process in welding under ceramic fluxes with an active deoxidizing agent, *Weld. Int.*, 1994, vol. 8, no. 10, pp. 808–809.
11. Kurlanov, S.A., Potapov, N.N., and Natapov, O.B., Relationship of physical and welding technological properties of fluxes for welding low alloy steels, *Weld. Int.*, 1993, vol. 7, no. 1, pp. 65–68.
12. Bublik, O.V. and Chamov, S.V., Advantages and shortcomings of ceramic (agglomerated) fluxes in comparison with fused fluxes used for the same applications, *Weld. Int.*, 2010, vol. 24, no. 9, pp. 730–733.
13. Gur'ev, S.V., Pletnev, Yu.M., and Murav'ev, I.I., Investigation of the properties of welded joints produced by welding in a gas mixture and under a flux, *Weld. Int.*, 2012, vol. 26, no. 8, pp. 646–648.
14. Parshin, S.G., Using ultrafine particles of activating fluxes for increasing the productivity of MIG/MAG welding of steels, *Weld. Int.*, 2012, vol. 26, no. 10, pp. 800–804.
15. Cruz-Crespo, A., Quintana-Puchol, R., Perdomo González, L., Gómez-Pérez, C.R., García-Sánchez, L.L., Ejiménez-Vielsa, G., and Cores-Sánchez, A., Carbothermic reduction of pirolusite to obtain carbon-bearing ferromanganese and slag suited to the development of welding materials, *Weld. Int.*, 2005, vol. 19, no. 7, pp. 544–551.
16. Barmin, L.N., et al., Effect of the composition of flux and welding wire on the properties of deposited metal of 05N4MYu type, *Weld. Int.*, 1989, vol. 3, no. 2, pp. 109–111.
17. Kazakov, Yu.V., Koryagin, K.B., and Potekhin, V.P., Effect of activating fluxes on penetration in welding steels thicker than 8 mm, *Weld. Int.*, 1991, vol. 5, no. 3, pp. 202–205.
18. Potapov, N.N., Feklistov, S.I., Volobuev, Yu.S., and Potekhin, V.P., A method of selecting fused fluxes in welding pearlitic-ferritic steels, *Weld. Int.*, 2009, vol. 23, no. 10, pp. 800–803.
19. Kozyrev, N.A., Kryukov, R.E., Kozyreva, O.E., Lipatova, U.I., and Filonov, A.V., Production of welding fluxes using waste slag formed in silicomanganese smelting, *IOP Conf. Ser.: Mater. Sci. Eng.*, 2016, vol. 125, pp. 1–6.
20. Kozyrev, N.A., Kryukov, R.E., Lipatova, U.I., and Kozyreva, O.E., On the use of slag from silicomanganese production for welding flux manufacturing, *IOP Conf. Ser.: Mater. Sci. Eng.*, 2016, vol. 150, pp. 1–9.
21. Kryukov, N.E., Kryukov, E.N., Kozyrev, N.A., Kryukov, R.E., and Kozyreva, O.A., RF Patent 2576717, *Byull. Izobret.*, 2016, no. 7.
22. Kryukov, N.E., Kryukov, E.N., Kozyrev, N.A., Kryukov, R.E., and Kozyreva, O.A., RF Patent 2579412, *Byull. Izobret.*, 2016, no. 10.

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