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Manufacturing of New Welding Fluxes Using Silicomanganese Slag

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Abstract. There were developed the composition and manufacturing technology of new welding flux using industrial products such as slag of silicomanganese production. The effect of fractional composition on welding and fabrication characteristics was studied. It was found that using of small-sized fracture of welding flux at a rate of 30-40% decreases the oxide non-metallic impurity rating of the weld and herewith doesn't affect its constituents.
To increase technical-and-economic indexes it was suggested to mix small-sized fracture and water glass. The use of ceramic flux made by mixing the dust fraction of silicomanganese slug with fraction size less than 0.45 mm and water glass provides the decrease of non-metallic impurity rating of the weld. Herewith the increase of its content from 15 to 40% doesn't have a significant influence on the non-metallic impurity rating of the weld and its constituents.

Introduction

Great attention in the world is paid to the issues of production, research and development of new welding fluxes [1 – 18]. It was proposed to use the slag of silicomanganese production for welding flux manufacturing [19, 20], the technology is protected by patents [21, 22]. The possibility of effective use of slag of silicomanganese production for welding flux manufacturingis considered in this paper.

Methods and materials

For the flux manufacturing was used the slag of silicomanganese production which chemical composition is presented in table 1. Alsointhefirstseriesofexperimentsthe possibility of use of differentslag fractions ratio was examined (table 2). Double-sided flux plain butt welding was carried out on the samples of 500×75 mm size and 16 mm thick made of sheet and plate steel type 09G2S. The welding process was performed with wire Sv-08GA with the use of welding machineASAW-1250 in modes: I_{weld} = 700 A; U_{arc} = 30 V; V_{weld} = 35 m/h.

Table 1 – Chemical composition of the slag of silicomanganese production

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	0.62	0.15-0.17	0.01

Samples were cut of the welded plates and the X-rays pectrometry of weld chemistry and metallographical tests of weld metal were conducted. Chemical composition of welding fluxes is presented in table 3. Chemical composition of slag crust is presented in table 4, chemical composition of weld metal is presented in table 5.

Table 2 –Fraction and component composition of fluxesin question

Sample	Ratio, %, of fractions, mm
1	100 % of fraction 0.45 – 2.5
2	95 % of fraction 0.45 – 2.5 + 5 % of fraction<0.45
3	90 % of fraction 0.45 – 2.5+ 10 % of fraction< 0.45
4	85 % of fraction 0.45 – 2.5 + 15 % of fraction< 0.45
5	80 % of fraction 0.45 – 2.5+ 20 % of fraction< 0.45
6	70 % of fraction 0.45 – 2.5+ 30 % of fraction< 0.45
7	60 % of fraction 0.45 – 2.5 + 40 % of 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

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

Table 4 – Chemical composition of slug crusts

Sample	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	absent	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	absent	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	absent	0.36	0.12	0.01
7	8.23	45.52	29.12	6.29	6.65	1.88	0.28	absent	0.26	0.12	0.01
8	8.19	48.79	24.42	4.82	5.14	2.45	3.64	absent	0.35	0.09	0.01
9	8.29	49.92	26.12	5.37	5.60	2.64	3.25	absent	0.37	0.10	0.01
10	8.16	48.25	26.32	5.22	6.02	2.17	2.12	absent	0.33	0.12	0.01
11	8.18	48.09	27.24	5.67	6.36	1.97	1.64	absent	0.34	0.12	0.01

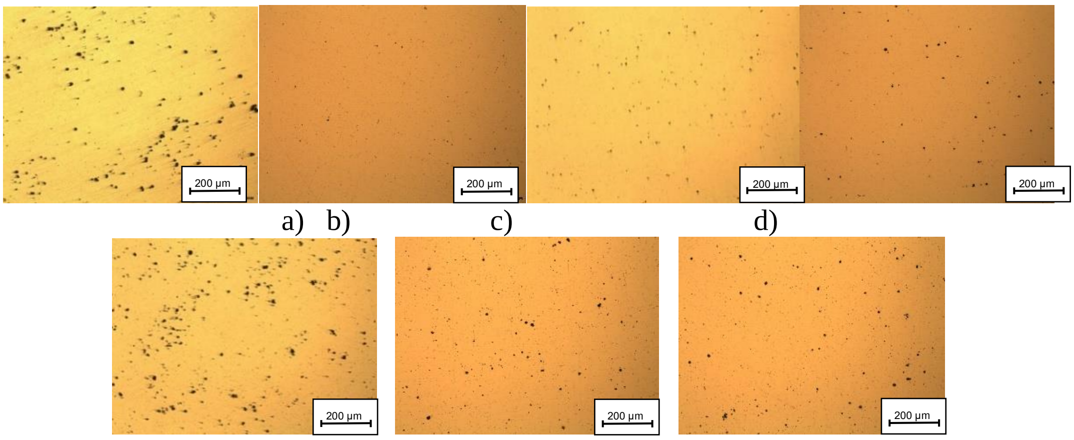
Table 5 – Chemical composition of weld metal

Sample	Content, %										
	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

Metallographical tests were conducted on micro sections without etching by means of optical microscope OLYMPUSGX-51 with optical magnification 100. Metallographical tests of metal structure in weld zone were conducted by means of optical microscopeOLYMPUSGX-51 in a bright-field in the magnification range of 500 after the etching of the samples surface in 4% nitricacid solution. Grain size was determined in accordance with GOST 5639 – 82.

Results

Theresultsofanalysisforpresenceofnon-metallicinclusions in the weld zonecarried out in accordance with GOST 1778-70, are presented in the figure 1 and in the table 6.



a) b) c) d)

e) f) g)

Fig. 1.Non-metallic inclusions in welding zone of the samples:
a – 1; b – 2; c – 3; d – 4; e – 5; f – 6; g – 7

Microstructures of weld metal are presented in the figure 2.

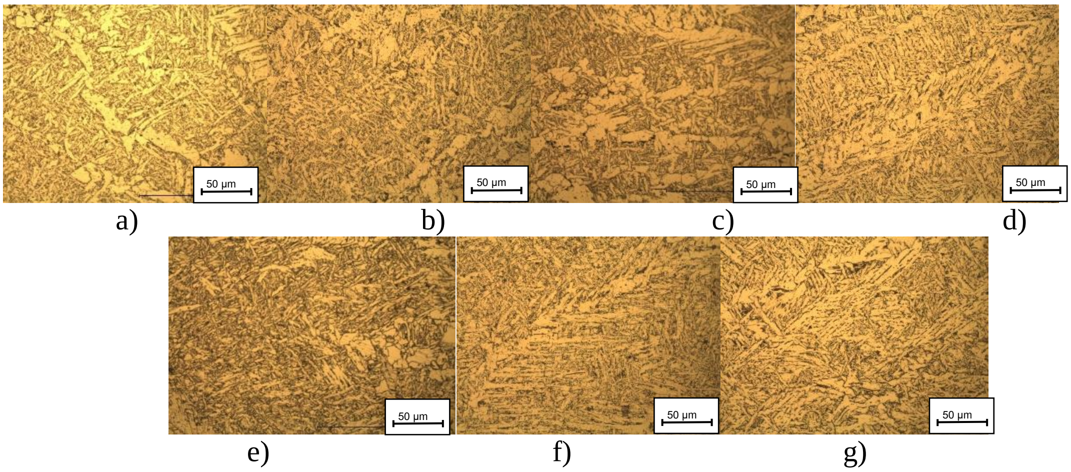


Fig. 2. Microstructures of samples welds :
a – sample 1; b –sample 2; c – sample 3; d – 4; e – 5; f – 6; g – 7

Samples were cut of the welded plates and their mechanical properties were determined. The results obtained by investigation of mechanical properties show the increase of impact strength (Figure 3).

The analysis of samples' mechanical properties shows that the optimal content of dust fraction with size less than 0.45 mm is 20-30%. This content of dust fraction with size less than 0.45 mm delivers the profitable set of mechanical properties of the samples cut of the welded plates.

In the weld metal structure of all samples' welds there is a ferrite presented in the form of unequiaxed grains elongated along the line of heat removal. There can be seen the transition from ferrite-pearlite uniform structure to the Widmanstatten ferrite-pearlite structure. However, relevant variation of grain sizes on a grain-size scale was not observed (table 6, 7).

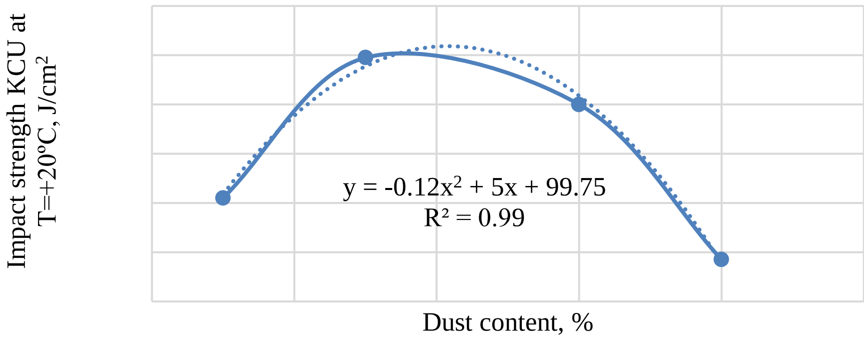


Fig. 3.The effect of dust fraction content (fraction size less than 0.45 mm) in the flux on the impact strength

In these cond series of experiments the possibility of use of ceramic flux made of water-glass-bonded silicomanganese slug's dust with fraction sizeless than 0.45 mm was studied. The production technique involved mixing silicomanganese slug and water glass in different proportions (table 2), drying, crush in gand size grading to get fractions 0.45-2.5 mm.

Table 6 – Non-metallicinclusions in weld zone

Sample	Non-metallic inclusions, scale number		
	Non deflecting silicates	brittle silicates	spot oxides
1	4b; 3b; 4a	3b	1a
2	2b; 1b; 3a; 4a	absent	1a; 2a
3	4b; 2b	absent	1a; 2a
4	2b; 4b	absent	1a; 2a
5	4b; 5b; 3b	absent	1a; 2a
6	2b; 1b; 2a; 2,5a	absent	1a; 2a
7	2b; 2a; 2,5a	absent	1a; 2a
8	2b; 1b; 2a; 2,5a	absent	1a
9	2b; 1b; 2a; 2,5a	absent	1a
10	2b;1b; 2a; 2,5a	absent	1a; 2a
11	2b; 2,5a	absent	1a, 2a

Table 7 – Welds' grain size according toGOST 5639-82

Sample	Grain size on 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 analys is of the mechanical properties of the samples cut of welded plates allowed to determine the optimal content of water glass in the flux (up to 20-30%) to achieve the profitable set of mechanical properties of the samples cut of the welded plates (figures 4, 5).

However, the examined fluxes are oxidizing fluxes and are created on the principles of silicon-manganese-oxidation-reduction reactions, therefore resultants of such reactions are oxidic compound of silicon and manganese. Consequently the non-metallic impurity rating of weld increases and hence the physical and mechanical properties decreases, especially at low temperatures. To decrease the impurity rating of weld and to increase mechanical properties we investigated the possibility of introduction of previously developed carbon and fluorine containing admixture FD–UFS in the new flux.

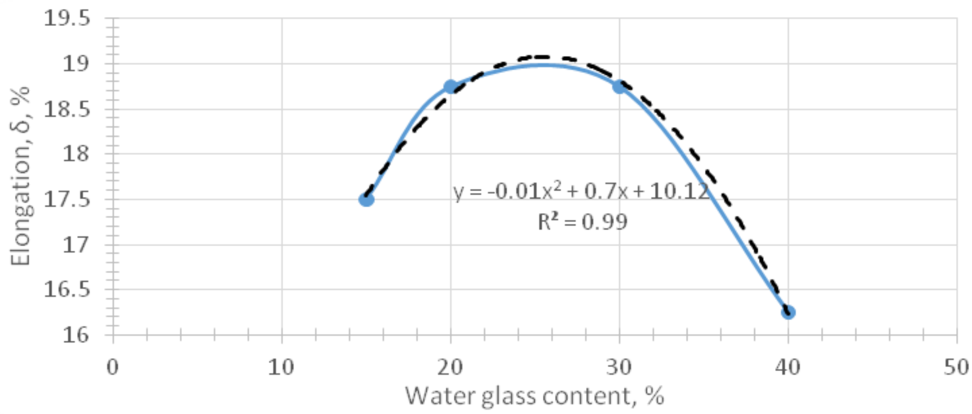


Fig. 4. The effect of water glass content in the flux on percentage elongation

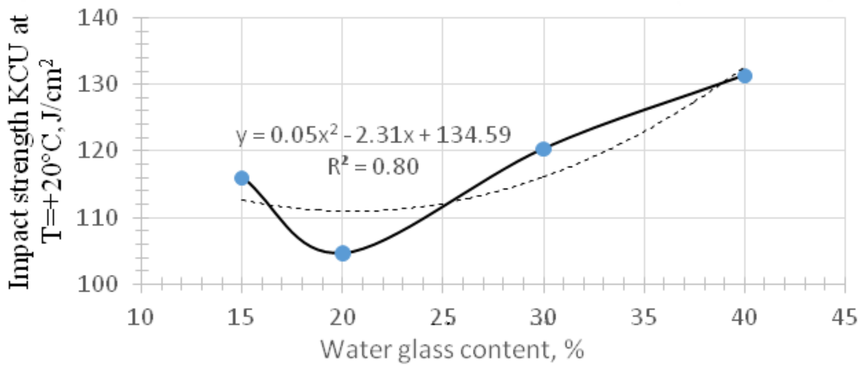


Fig. 5. The effect of water glass content in the flux on the impact strength

In the experiments flux-admixture was added at the ratio of 2, 4, 6, 8 % accordingly.

Chemicalcomposition of examined mixtures is presented in table 8, composition of slug crusts is presented in table 9, chemical composition of welds' metal is presented in table 10.

Table 8 – Chemical composition of examined flux mixtures, %

FD–UFS content in the flux, %	FeO	MnO	Ca	SiO_2	Al_2O_3	MgO	Na_2O	K_2O	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	0.24	0.01	absent	1.95
6	0.81	7.68	16.79	43.64	11.27	5.71	2.25	0.65	0.34	0.01	0.003	4.04
8	0.46	7.46	16.00	43.64	11.86	5.56	2.30	0.60	0.33	0.01	0.002	3.96

Table 9 – Chemical composition of slug crusts, %

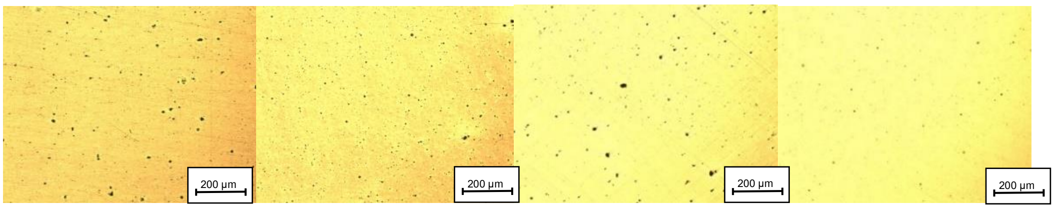
FD–UFS content in the flux, %	FeO	MnO	Ca	SiO_2	Al_2O_3	MgO	Na_2O	K_2O	S	P	ZnO	F
2	2.21	7.25	15.55	38.09	9.39	8.63	0.49	0.57	0.12	0.006	0.002	0.94
4	2.28	7.39	16.90	42.00	9.76	5.77	0.76	0.62	0.15	0.008	0.002	1.12
6	2.24	7.20	16.06	39.94	11.15	7.14	1.09	0.60	0.17	0.008	0.002	1.53
8	2.36	7.14	14.70	42.87	12.40	5.57	1.34	0.57	0.20	0.008	0.002	1.88

Therefore, the metal of the weld which has been made with flux without admixtures has the highest non-metallic impurity rating. The introduction of admixture FD–UFS decreases the non-metallic impurity rating and also decreases the impurities' size and number. Speaking of the examined ratio, the highest effect on the non-metallic impurity rating has the 8% amount of admixture.

Table 10 – Chemical composition of welds' metal

FD–UFS content in the flux, %	Mass fraction of the element %									
	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

The results of analys is for presence of non-metallic inclusions in the weld zone carried out in accordance withGOST 1778 – 70 are presented on figure 6 and in the table 11.



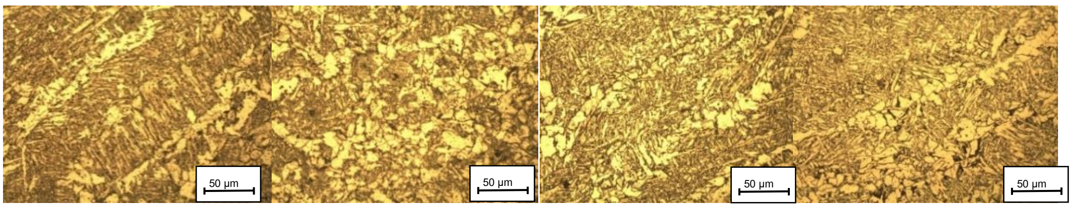
a) b) c) d)

Fig. 6.Non-metallicinclusions in the weld zone of the samples with admixture ratio, %: a) 2; b) 4; c) 6; d) 8

Table 11 – Non-metallicinclusionsinweldzone

FD–UFS content in the flux, %	Non-metallic inclusions, scale number		
	Non deflecting silicates	brittle silicates	spot oxides
2	2b, 4b, 5a	absent	1a, 2a
4	2b, 4b	absent	1a, 2a
6	2b, 4b, 1b	absent	1a, 2a
8	2b	absent	1a, 2a

Microstructure of samples' welds is presented on figure 7. It was found out that introduction of admixture at a rate no more than 8% has no effect on the size and morphology of constituents.



a) b) c) d)

Fig. 7.Microstructureofwelds of the samples with admixture ratio, %: a) 2; b) 4; c) 6; d) 8

The examination of mechanical properties has shown that as the amount of admixture increases the level of properties also increases (figure 8). The conducted researches formed the basis for RF patents [21, 22].

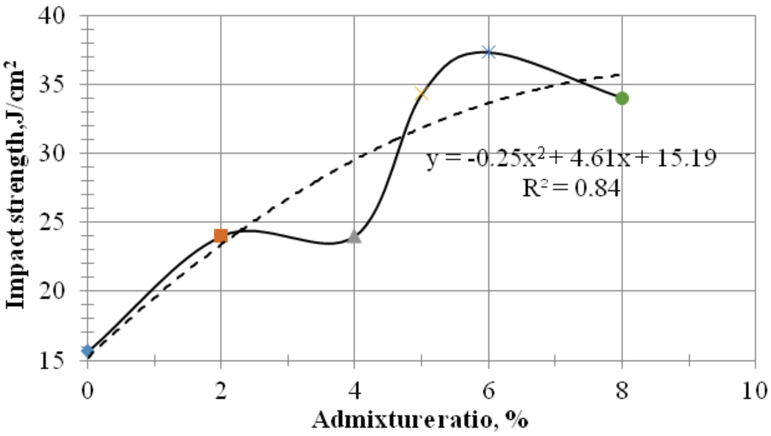


Fig. 8.Effect of admixture FD–UFS ratio in the flux on the impact strength (KCV at T=-20 ºC)

Conclusions

1. The possibility in principle of use of slag of silicomanganese production for welding flux manufacturing was shown.
2. It is possible to use in the fluxes up to 30% of small-sized fracture(less than 0.45 mm). This content of dust fracture in the flux is optimal to achieve the profitable set of mechanical properties of the samples cut of the welded plates.
3. The optimal content of water glass in the flux allows to achieve the profitable set of mechanical properties is 20-30%.
4. To decrease the non-metallic impurity rating of weld and to increase mechanical properties of the weld it was suggested to introduce in the fluxes carbon-fluorine containing admixture FD–UFS at the ratio 2-8%. The introduction of admixture decreases the non-metallic impurity rating and also decreases the impurities' size.

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