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Production of Welding Fluxes Using Waste Slag Formed in Silicomanganese Smelting

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Abstract: The possibility in principle of using slag, which is formed in the silicon-manganese smelting process, in producing welding fluxes is shown. The composition of and technology used for a new fused flux has been designed. A comparative evaluation of the new flux and the widely used AN-348 type flux was done. It has been proved that the new flux has high strength properties.

1. Introduction

Currently, much attention is paid to the development of new fluxes and additions, with analyzing the effect of flux chemical compositions on mechanical properties of a weld, and the content of oxygen and nonmetallic elements in welds. [1-6].

Today, the AN-348 type fused flux produced in Ukraine is widely used in welding and surfacing low alloy steels in Russia [7, 8].

It should be noted that such fluxes are oxidative, and their production is based on silicomanganese redox reactions, and in this connection the products of these reactions are the oxides of silicon and manganese. As a result, using such fluxes in welding promotes impurities, such as nonmetallic inclusions contained in weld metal and, as a consequence, physical and mechanical properties of a weld are negatively affected. Carbon-fluorine additives of a FD-UFS type were suggested for the removal of impurities in weld metal to improve its mechanical properties [5, 6]; this allows de-oxidation of the weld metal with carbon, causing significant lowering in the content of non-metallic elements represented by oxides.

Another significant disadvantage of using fused fluxes is their high cost, because natural materials are expansive and costs associated with mixtures, prepared for smelting flux in specially designed melting facilities, are high.

The use of metallurgical wastes, including the slag formed in the silicomanganese smelting process, for the production of welding fluxes is one of the ways to reduce the cost of welding fluxes. Analysis of published data shows that, when smelting silicon-manganese alloys, the slag, which is dumped, has a chemical composition generally in line with the requirements to the chemical composition of welding fluxes. Thus, according to work in reference [9], the slag contains: 14–16% MnO; 45–60% SiO_2; 7–8% Al_2O_3; 12–15% CaO; 3–4% MgO with ratio of CaO/SiO_2 = 0.52–0.58.

According to the data given in [10]: 47–49% SiO_2; 18–20% MnO; 12.2–14% CaO; 7–8% Al_2O_3; 2.9–3.1% MgO. Following [11]: 6.2–8.5% MnO; 45–47% SiO_2; 18–23% CaO; 9.2–11.6% Al_2O_3; 7.6–12.1% MgO; 0.3–0.7% FeO; ≤ 3% C. In the work referenced in [12]: 47–49% SiO_2; 18–20% MnO; 12.5–14% CaO; 7–8% Al_2O_3; 2.9–3.1% MgO. In the work referenced in [13]: 3.2–4.5% MnO; 43–47% SiO_2; 22–30% CaO; 12–16% Al_2O_3; 6–10% MgO; 0.3–0.7% FeO; ≈ 3,5% C. It should also be noted that, when silicomanganese alloys are obtained using the carbothermic process, up to 20.3% of manganese contained in raw materials may pass to the slag [13].

Based on these assumptions, we discussed that slag wastes formed in silicomanganese processing could be used in the production of a flux suitable for welding and surfacing of low-alloy steels.

2. Methods of Research

When producing the flux intended to be used in welding, the slag was used that was formed by the silicomanganese smelting in ore-thermal furnaces, employing the carbothermic continuous process. Table 1displays the chemical composition of slag. The product was smelted according to the conventional process scheme. The charge mixture consisted of manganese ore, quartzite, iron chips and coke fines. Ferroalloys (silicomanganese) were tapped with the slag into the ladle. After pouring silicomanganese, the slag was cooled while pouring into the ladle.

Table 1 – Chemical composition of silicomanganese slag

Material	Weight, %											
	Al_2O_3	CaO	SiO_2	FeO	MgO	MnO	F	CaF_2	Na_2O	K_2O	S	P
Si-Mo slag	10.61	18.62	50.55	1.55	8.03	9.63	0.38	-	0.41	0.61	0.13	0.05
AN-348	≤6	≤12	40-44	0.5-2.0	≤7	31-38	-	3-6	-	-	≤0.12	≤0.12

Under a laboratory environment, the flux was made by crushing, screening and sieving into fractions. Optimal fractions and their proportions were taken into consideration. Submerged arc welding was performed on samples of metal sheet in 09G2S steel using Sv-08GA wire and an ASAW-1250 welding machine. Of the welded plates, test specimens were cut to analyze micro- and macrostructure, and mechanical behaviour (ultimate tensile strength 6_B, MPa yield strength 6_T, MPa, elongation δ,%; impact strength KCV at -20 °C, J/cm2).

For the examination, the following fractions were used: less than 0.45 mm; 0.45-2.5 mm; 2.5-5 mm; 5-10 mm. Welding was performed with the following characteristics: Isv = 700 A; Ud = 30 V; Vsv = 35 m/h, and surfacing was done with: Isv = 410 A; Ud = 27; Vsv = 30 m/h. The tests have proved that 2.5-5 mm and 5-10 mm fractions do not ensure the quality of a weld surface (slag inclusions and high porosity of the weld), the fraction of less than 0.45 mm causes the formation of some kind of pitted surface of on the weld surface; the optimal fraction is 0.45-2.5 mm (Figure 1-4).

Figure 1 – Quality of the weld surface with a 0.45–2.5 mm fraction used in welding

Figure 2 – Quality of the weld surface with a 2.5–5 mm fraction used in welding

Figure 3 – Quality of the weld surface with a 5–10 mm fraction used in welding

Figure 4 – Quality of the weld surface with a fraction of less than 0,45mm used in welding

The chemical composition of the crust (slag) on top of the weld after flux cored welding, with the flux obtained using the slag from silicomanganese processing, is given in Table 2.

Table 2 – Chemical composition of the slag crust

Wt, %										
Al_2O_3	CaO	SiO_2	Fe_2O_3	MgO	MnO	F	Na_2O	K_2O	S	P
10.01	18.02	47.7	2.83	7.09	9.42	0.34	0.39	0.61	0.12	0.02

3. Results and Discussion

Welds made using the flux that was produced using silicomanganese slag and the widely used AN-348 flux were analyzed relating to their mechanical properties. The comparative evaluation has showed that the strength of the welded joints when using the new flux is significantly higher, but the value of impact strength at negative temperatures is not satisfactory; the same is observed using the AN-348 flux. When adding a FD-UFS fluxing agent in different proportions (1-5%) to the experimental flux, the values of impact strength KCV at -20 °C are considerably higher. The results of mechanical tests are given in Figures 5-8 and Table 3.

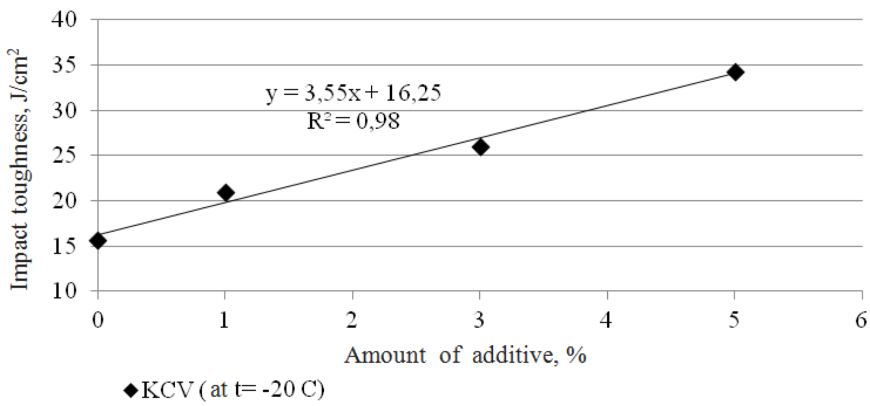

Figure 5 – Change in impact strength KCV of the weld metal at T = -20 °C with the amount of carbon-fluorine additions to flux

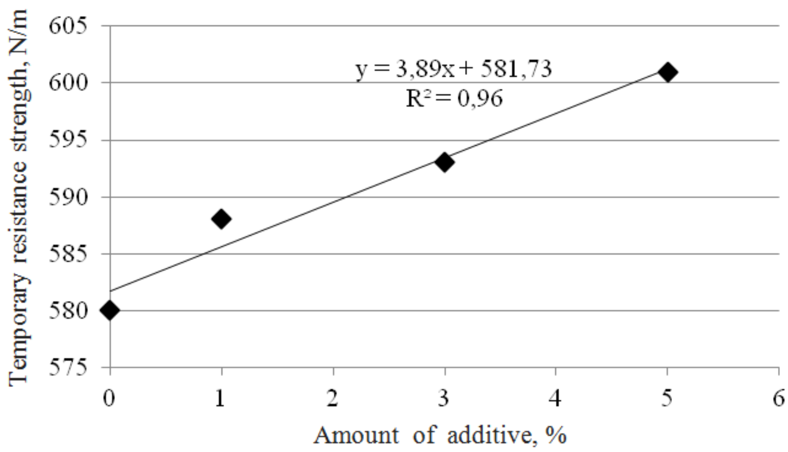

Figure 6 – Change in ultimate tensile strength with the amount of carbon fluorine additions to flux

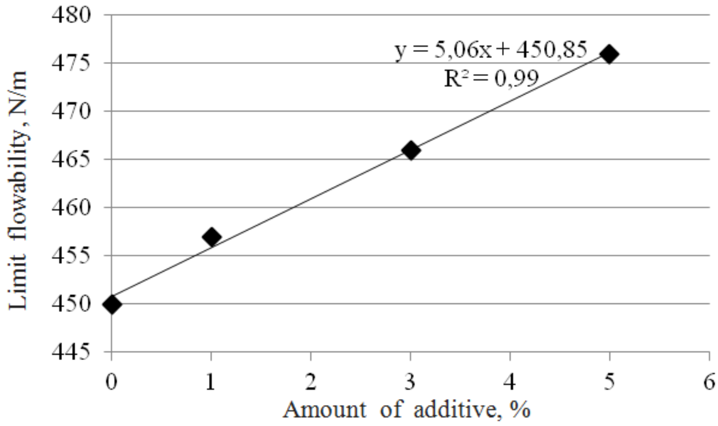

Figure 7 – Change in yield strength with the amount of carbon-fluorine additions to flux

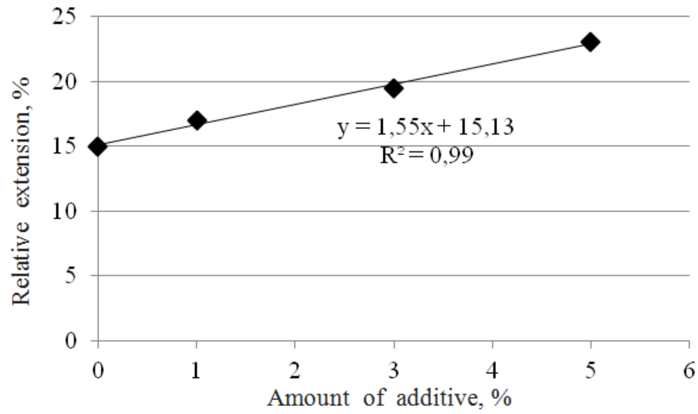

Figure 8 – Change in elongation with the amount of carbon-fluorine additions to flux

Table 3 – Mechanical properties of weld metal

Weld; Flux-cored welding	Ultimate tensile strength (Ϭв), MPa	Yield strength (Ϭт), MPa	Elongation (δ), %	Impact strength KCV at T= –20 °C, J/cm² (weld)
AN-348	535* 530-543**	360 355-368	25 24-26	18 16-21
Silicomanganese slag	580 576-583	450 447-452	15 14-16	16 15-17
Silicomanganese slag + 1 % FD-UFS	588 585-592	457 451-463	17 15,5-18	21 18-23
Silicomanganese slag + 3 % FD-UFS	593 590-596	466 463-469	19,5 19-20	26 20-32
Silicomanganese slag + 5 % FD-UFS	601 597-604	476 472-479	23 22-24	35 26-42

* - average values; ** - minimum and maximum values.

Conclusions

1. As laboratory experiments have shown, the use of slag, formed in the silicon-manganese smelting process, for the production of welding fluxes is possible in principle. Currently, the welding technology with using the experimental flux is under testing in the pilot-scale manufacturing conditions.

2. Based on the experiments performed, the dependences, describing the effect of carbon-fluorine additions to flux on the mechanical properties of welds, were obtained.

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