On the use of slag from silicomanganese production for welding flux manufacturing

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Abstract. The technologies for manufacturing of welding fluxes with the use of slag from silicomanganese production and dust of gas purification from aluminum production are developed. The new compositions and production technology of welding fluxes are offered. The comparative evaluation of the new compositions and widely used AN-348 flux is provided. It is shown that the quality of submerged arc welding with the use of the developed flux composition is significantly better than the submerged arc welding with AN-348 flux. The effect of fractional composition on high-quality performance of the weld is investigated. The macro- and microstructures, nonmetallic inclusions and the mechanical properties of the weld are examined. It is shown that the introduction of carbon-fluorine containing additive into the flux, based on the dust of gas purification from aluminum production, can significantly improve the whole complex of mechanical properties of the weld, especially characteristics of impact hardness at low temperatures. The conducted research served as a basis for development of submerged arc welding technologies protected by the patents of the Russian Federation.

1. Introduction
Much attention is paid to development of new fluxes and additives to them. A special role is played by the study of the chemical composition influence on the mechanical properties of the weld, on the level of gas saturation and contamination of weld with nonmetallic inclusions of endogenous and exogenous type [1-3]. The existing fluxes for welding of low alloyed steels for weld fused fluxes according to the State Standards (GOST) 9087-81, GOST 52222-2004 and for ceramic fluxes in accordance with GOST 28555-90 provide with the high content of total oxygen and, consequently, an increased amount of non-metallic inclusions in the joints. Today, reduction of non-metallic inclusions in welds during automatic submerged arc welding is achieved by using low oxidizing fluxes. However, such fluxes have poor welding characteristics and are rarely used in welding of low alloyed steels. Moreover, the use of oxidation fluxes leads to weld metal saturation with oxygen due to silica- and manganese-reducing processes.

Currently, the applied alloying systems [4] in welding due to silica- and manganese-reducing processes (1 – low carbon electrode wire and high-manganese flux with high silica content; 2 – lowcarbon wire and high-silicon (acid) flux; 3 – medium manganese electrode wire and medium manganese acid flux) have several disadvantages. The use of silicon and manganese as deoxidizers...
results in the formation of various oxide inclusions, which, due to the transience of the welding process, does not always manage to surface and assimilate by slag, so the concentration of free and bound oxygen in the weld metal is quite high, and the decrease in the values of impact strength of the weld metal especially at low temperatures is observed. To eliminate weld metal contamination and improve the mechanical properties we proposed the use of carbon-fluorine containing additive of grade FD-UFS [5-8], which allows us to carry out deoxidation of the weld with carbon and significantly reduce the contamination level with non-metallic oxide inclusions.

Another significant disadvantage of fused fluxes is their high cost due to the use of expensive natural materials and the costs associated with the preparation of the charge to be melted and flux smelting in special units.

To reduce costs of welding fluxes the waste from metallurgical production, particularly, the slag from silicomanganese production is used. Analysis of the published data shows that in the production of silicomanganese alloys the dumping ladle slags are generated, having the chemical composition suitable for welding fluxes manufacturing. Thus, according to [9] the slag contains: 14–16% MnO; 45–60% SiO2; 7–8% Al2O3; 12–15% CaO; 3–4% MgO with ratio CaO/SiO2=0,52–0,58. From [10]: 47–49% SiO2; 18–20% MnO; 12.2–14% CaO; 7–8% Al2O3; 2.9–3.1% MgO. From [11]: 6.2–8.5% MnO; 45–47% SiO2; 18–23% CaO; 9.2–11.6% Al2O3; 7.6–12.1% MgO; 0.3–0.7% FeO; ≤3% C. In work [12]: 47–49% SiO2; 18–20% MnO; 12.5–14% CaO; 7–8% Al2O3; 2.9–3.1% MgO. In [13]: 3.2–4.5% MnO; 43–47% SiO2; 22–30% CaO; 12–16% Al2O3; 6–10% MgO; 0.3–0.7% FeO; ≤3.5% C. It should also be noted that for carbothermic production of silicomanganese slag may contain up to 20.3% of manganese from charge material [13].

Today in Russia for welding and surfacing of low-alloyed steels the fused fluxes AN-348 produced in Ukraine are widely used [14, 15], therefore, the attention to the issue of import substitution is growing. Based on this fact we considered the possibility of using the slag from silicomanganese production manufacturing flux for welding and surfacing of low-alloyed steels.

2. Experimental research and results
The study was conducted using the flux made of ladle slag from silicon-manganese production smelted in the ore-thermal furnaces by carbothermic method of continuous process, and dust of gas purification from aluminum production (Table 1). Dust of gas purification was mixed with the liquid glass and used for manufacturing of carbon-fluorine containing additive PD-UVC according to the technology protected by the patents of the Russian Federation [16, 17].

| Component                          | MnO  | SiO2  | CaO  | MgO  | Al2O3 | FeO  | Na2O | K2O  | F    | S    | P    | C    |
|------------------------------------|------|-------|------|------|-------|------|------|------|------|------|------|------|
| slag from silicomanganese production| 8.01 | 46.46 | 22.85| 6.48 | 9.62  | 0.38 | 0.36 | 0.62 | 0.76 | 0.17 | 0.01 |
| dust of gas purification from aluminum production| 0.6  | 2.33  | 2.1  | 0.8  | 43.27 | 2.1  | 10.6 | 0.8  | 23.6 | 0.38 | 0.10 | 12.5 |

Testing of welding modes was performed by ASAW-1250 welding tractor with the use of welding wire Sv-08GA, diameter 4 mm. Butt submerged arc welding of plates 500×75 mm of 16 mm thick was conducted by double-sided welding without bevel. Welding mode: Iw = 700 A; Ua = 30; Vw = 35 m/h, surfacing mode: Iw = 410 A; Ua = 27; Vw = 30 m/h. In the study of the influence of fractional composition on the quality of the weld bead, the following fractions of the ladle slag from silicomanganese production were used: less than 0.45 mm; 0.45-2.5 mm; 2.5-5 mm; 5-10 mm.
The experiments determined that fractions of 2.5-5 mm, 5-10 mm do not provide a qualitative weld (high porosity of weld and slag inclusions), a fraction less than 0.45 mm is associated with obtaining of some “cratering” of the surface, the optimal fraction is 0.45-2.5 mm (Figure 1).

In the future the flux manufacturing was conducted by mixing of fractions 0.45-2.5 mm of ladle slag from silicomanganese production with different percentages of carbon-fluorine containing additive (1st sample – without FD-UFS and from 2nd to 5th samples, 2, 4, 6, 8% FD-UFS respectively.). The chemical analysis of welds is presented in Table 2.

Table 2. Chemical composition of welds.

| Sample | C  | Si  | Mn  | Cr  | Ni  | Cu  | Al  | S     | P     |
|--------|----|-----|-----|-----|-----|-----|-----|-------|-------|
| 1      | 0.09 | 0.61 | 1.41 | 0.02 | 0.06 | 0.09 | 0.022 | 0.020 | 0.008 |
| 2      | 0.09 | 0.62 | 1.40 | 0.02 | 0.06 | 0.09 | 0.023 | 0.020 | 0.008 |
| 3      | 0.10 | 0.60 | 1.34 | 0.02 | 0.06 | 0.09 | 0.013 | 0.023 | 0.009 |
| 4      | 0.12 | 0.66 | 1.43 | 0.02 | 0.06 | 0.10 | 0.012 | 0.027 | 0.008 |
| 5      | 0.13 | 0.65 | 1.36 | 0.02 | 0.06 | 0.09 | 0.013 | 0.024 | 0.008 |

Metallographic analysis was performed using microscope OLYMPUS GX-51 in bright field at magnifications ranging from ×100 to ×1000 after etching in 4% solution of nitric acid. The grain size was determined in accordance with GOST 5639-82 at magnification ×100. Examination of samples for the presence of nonmetallic inclusions was carried out in accordance with GOST 1778-70. The polished surface was examined at ×100 magnification using microscope OLYMPUS GX-51.
Figure 1. The quality of the weld surface (a – fraction 0.45-2.5 mm, b – 2.5-5 mm, c – 5-10 mm, d – less than 0.45 mm).

The resulting welds are shown in Figure 2. Metallographic analysis revealed that the welds of the investigated samples have a ferrite-pearlite structure of widemanstatten character with separate zones of ferrite of acicular structure. In some areas there is striation of ferrite-pearlite structure (Figure 3).

The grain size in the weld structure of sample No.1 according to the grain scale is No 4, 5. The grain size in the weld structure of sample No.2 and No.3 corresponds to 5, 6 and 7. The grain size for samples No.4 and No.5 corresponds to 5 6, 7. Thus, it was found that increased levels of FD-UFS content in the studied fluxes compositions contributes to grain refinement of the weld.

Studies of the nature of non-metallic inclusions showed that in the weld zone of samples there were non-deformable silicates, fragile silicates, point oxide and lineage oxides (Figure 4).
Figure 2. Beads of samples (a – sample No.1; b – sample No.2; c – sample No.3; d – sample No. 4; e – sample 5).

In the weld zone of sample No.1 the spot oxides were found of 1 a point, the non-deformable silicates, mainly of points 4 b and 3 b, and rarely of point 4 a, fragile silicates, less common, of point 3 b. In the weld zone of samples No.2 and No.3 there are non-deformable silicates of points 2 b, 4 b, and spot oxides of point 1 a.
Figure 3. The weld microstructure of the examined samples (a – sample No. 1; b – sample No. 2; c – sample No. 3; d – sample 4; e – sample No. 5).

In the weld zone of sample No.4 non-deformable silicates of points 2 b, 1 b and spot oxides of point 1 a were found. In the weld zone of sample No.5 there are non-deformable silicates of point 2 b and spot oxides of point 1 a. Introduction of flux carbon-fluorine containing additive (PD UFS) into the flux reduces the contamination level of the weld with non-metallic inclusions and reduces their quantity and sizes (Figure 4). The results of mechanical tests are given in Table 3 and in Figures 5-8. The comparative evaluation of mechanical properties of the flux with the widely used flux AN-348 (GOST 9087-81) showed that the strength properties of the new flux is much higher, however, the value of impact strength at negative temperatures is not satisfactory, which is observed during use of flux AN-348. Introduction of additive FD-UFS into the flux in different ratios (1-5%) significantly increases values of impact strength KCV at a temperature −20 °C.
Figure 4. The nature of nonmetallic inclusions in the weld zone of samples.

![Figure 4](image)

Figure 5. Change of impact strength of metal weld KCV $T = -20 \, ^\circ C$ depending on the content of carbon-fluorine-containing additive in the flux.

![Figure 5](image)

$y = 3.55x + 16.25$

$R^2 = 0.98$

Figure 6. Change in ultimate tensile strength depending on the content of carbon-fluorine-containing additive in the flux.

![Figure 6](image)

$y = 3.89x + 581.73$

$R^2 = 0.96$
Figure 7. Change in yield strength depending on the content of carbon-fluorine-containing additive in the flux.

Figure 8. Change in percentage of elongation on the amount of carbon-fluorine-containing additive in the flux.

Table 3. Mechanical properties of welds.

| Flux                | Ultimate tensile strength, MPa | Yield strength, MPa | Percentage of elongation (δ), % | Impact strength KCV at T= - 20°C, J/cm² (weld) |
|---------------------|-------------------------------|---------------------|---------------------------------|-----------------------------------------------|
| AN-348              | 535                           | 360                 | 25                              | 18                                           |
|                     | 530-543                       | 355-368             | 24-26                           | 16-21                                         |
| Slag of silicomanganese | 580                           | 450                 | 15                              | 16                                           |
|                     | 576-583                       | 447-452             | 14-16                           | 15-17                                         |
| Slag of silicomanganese + 1 % FD-UFS | 588                           | 457                 | 17                              | 21                                           |
|                     | 585-592                       | 451-463             | 15,5-18                         | 18-23                                         |
| Slag of silicomanganese + 3 % FD-UFS | 593                           | 466                 | 19,5                            | 26                                           |
|                     | 590-596                       | 463-469             | 19-20                           | 20-32                                         |
| Slag of             | 601                           | 476                 | 23                              | 35                                           |
silicomanganese + 5% FD-UFS

|                        | 597-604 | 472-479 | 22-24 | 26-42 |
|------------------------|---------|---------|-------|-------|

*numerator – average values; denominator – minimum and maximum values.

3. Conclusion
As a result of laboratory experiments the conceptual possibility for use of slag from silicomanganese production in manufacturing of welding fluxes was shown. The obtained fluxes are patented in the Russian Federation patents [18, 19].

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