Use of barium – strontium modifier in manufacturing welding flux based on silicomanganese slag for welding and surfacing mining equipment

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Abstract. The paper discusses the possibility in principle of barium-strontium modifier application as a refining and gas-protective additive for welding fluxes based on silicomanganese slag for surfacing mining equipment. In the experiments the barium-strontium flux additive was used, prepared in two ways: barium-strontium modifier mixed with liquid glass and the dust of barium-strontium modifier with a fraction less than 0.2 mm. The additives were mixed at a ratio of 2-10% from weight of silicomanganese slag. It is shown that the use of a mixture of barium-strontium modifier with liquid glass as an additive is more preferable to the use of additive as a dust. It was established that the use of not more than 8% of a barium-strontium additive is optimal from the point of view of metal contamination with nonmetallic inclusions.

1. Introduction
The development of materials and the use of recovery technology that significantly increase the wear resistance of the working surfaces of machines and mechanisms of mining equipment exposed to abrasive and impact wear during operation is an important task. The most promising methods of recovery include the use of submerged-arc welding of the parts wear surfaces.

To restore the mining equipment, welding fluxes such as ANF-6-1, AN-348, AN-60, AN-20, AN-28 are used. To reduce the costs for restoration of mining equipment, the application of a new welding flux based on wastes from metallurgical production such as silicomanganese slag and flux – additives containing barium and strontium modifier is suggested [1-18]. The studies on the introduction of a barium-strontium modifier additive into welding fluxes based on silicomanganese slag, as well as the quality of the weld beads produced, were studied previously [19-20], the further studies are presented in this paper.

2. Methods of research
The chemical composition of the welded samples was determined according to the state standards GOST 10543-98 by the X-ray fluorescence method on XRF-1800 spectrometer and by the atomic-emission method using DFS-71 spectrometer. Investigation of longitudinal samples of the deposited layer for the presence of nonmetallic inclusions was performed in accordance with GOST 1778-70 using the optical microscope OLYMPUS GX-51 in a bright field within the range of magnifications ×100.
To produce the flux, slag from silicomanganese production with the chemical composition given in table 1 was used. The preparation flux additive containing barium-strontium modifier with the chemical composition (table 2) was carried out by mixing the barium-strontium modifier with liquid glass in a ratio of 75% and 25%, respectively. After that, the mixture was kept at a room temperature for 24 hours, dried in the oven at 300 °C, further cooled, crushed and sieved to obtain fraction of 0.45-2.5 mm. Further, the flux and flux-additives were mixed in various proportions. The investigated flux and flux-additive ratios are given in table 3. The silicomanganese slag with the fraction 0.45-2.5 mm was applied in the experiments. In the first option (with liquid glass), the additive was introduced in an amount of 2, 4, 6, 8, 10% (corresponding samples M2, M4, M6, M8, M10). According to the second option, the additive (dust) was introduced in an amount of 2, 6, 8, 10% (corresponding samples M21, M61, M81, M101). The flux made of silicomanganese slag without additives (M) was used for comparison.

The surfacing was performed on samples with sizes 300 × 150 mm and 20 mm in thickness from sheet steel grade 09G2S. The process was carried out using S-08GA welding wire by ASAW-1250 welding tractor in the following modes: I = 680 A; U = 28 V; V = 28 m/h.

The samples were cut from the welded plates, and the X-ray spectral analysis of the deposited layer composition and metallographic studies of the deposited layer were carried out. The chemical composition of the welding flux is provided in table 4. The chemical composition of the slag crust is given in table 5, the chemical composition of the weld metal is given in table 6.

**Table 1.** Chemical composition of silicomanganese slag.

| Content, % | Al₂O₃ | CaO | SiO₂ | FeO | MgO | MnO | F | Na₂O | K₂O | S | P |
|------------|-------|-----|------|-----|-----|-----|---|------|-----|---|---|
| 6.91-9.62  | 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 | 0.62-0.17 | 0.15-0.01 |

**Table 2.** Chemical composition of barium – strontium modifier.

| Content, % | BaO | SrO | CaO | SiO₂ | MgO | K₂O | Na₂O | Fe₂O₃ | MnO | Al₂O₃ | TiO₂ | CO₂ |
|------------|-----|-----|-----|------|-----|-----|------|-------|-----|-------|-----|-----|
| 13.0-19.0  | 13.0-19.0 | 3.5-7.5 | 17.5-25.5 | 19.8-29.8 | 0.7-1.1 | 2.5-3.5 | 1.0-2.0 | 1.5-6.5 | 1.9-3.9 | 0.7-1.1 | 16.0-20.0 |

**Table 3.** Investigated ratios of flux – flux-additives, %.

| Flux marking | The amount of barium-strontium additive, wt% | The amount of silicomanganese slag, wt% |
|--------------|---------------------------------------------|----------------------------------------|
|              | With liquid glass | Dust |                                      |
| M            | -               | -   | 100                                    |
| M2           | 2               | -   | 98                                     |
| M4           | 4               | -   | 96                                     |
| M6           | 6               | -   | 94                                     |
| M8           | 8               | -   | 92                                     |
| M10          | 10              | -   | 90                                     |
| M21          | -               | 2   | 98                                     |
| M61          | -               | 6   | 94                                     |
| M81          | -               | 8   | 92                                     |
| M101         | -               | 10  | 90                                     |

As it can be seen from figures 1-4, when the additive flux is introduced, barium, strontium are reduced, and the concentration of sulfur and phosphorus get lower. Investigation of longitudinal
samples of the deposited layer for the presence of nonmetallic inclusions was carried out on thin sections without etching by OLYMPUS GX-51 optical microscope with a magnification × 100 comparing with the reference scales according to GOST 1778-70.

The presence of non-deformable silicates, spot and sulfide oxides was established in the weld metal (figure 5) after studying the nature of its contamination with nonmetallic inclusions. The characteristics of nonmetallic inclusions of the deposited layer are given in table 5.

It was shown that when using a mixture of barium-strontium modifier in the amount 2-8% with a liquid glass, the degree of weld metal contamination with nonmetallic inclusions is less, in comparison with the absence of liquid glass in the additive, as well as 10% of the liquid glass in it.

### Table 4. Chemical composition of the flux.

| Flux | FeO | MnO | CaO | SiO₂ | Al₂O₃ | MgO | Na₂O | K₂O | S | P |
|------|-----|-----|-----|------|-------|-----|------|-----|---|---|
| M    | 0.50| 7.97| 31.34| 46.09| 6.61  | 5.74| 0.40 | 0.01| 0.33| 0.011|
| M2   | 1.39| 7.68| 31.27| 46.31| 6.48  | 5.40| 0.52 | 0.04| 0.20| 0.022|
| M4   | 0.77| 7.69| 30.56| 46.11| 6.42  | 5.42| 0.49 | 0.03| 0.38| 0.022|
| M6   | 1.11| 7.12| 29.27| 45.52| 6.87  | 4.75| 0.75 | 0.20| 0.17| 0.037|
| M8   | 1.04| 7.14| 31.65| 43.93| 6.22  | 3.71| 0.79 | 0.27| 0.13| 0.044|
| M10  | 2.08| 7.09| 30.16| 43.90| 7.17  | 3.58| 0.62 | 0.20| 0.12| 0.027|
| M21  | 1.32| 8.14| 32.09| 45.19| 6.20  | 5.35| 0.36 | 0.01| 0.43| 0.014|
| M61  | 0.33| 8.02| 30.97| 46.38| 6.71  | 6.01| 0.29 | 0.01| 0.18| 0.013|
| M81  | 1.89| 7.90| 30.79| 40.07| 5.71  | 3.03| 0.48 | 0.57| 0.13| 0.090|
| M101 | 1.01| 7.22| 31.62| 44.99| 6.71  | 3.29| 0.40 | 0.32| 0.14| 0.061|

### Table 5. The chemical composition of slag crusts.

| Flux | FeO | MnO | CaO | SiO₂ | Al₂O₃ | MgO | Na₂O | K₂O | S | P |
|------|-----|-----|-----|------|-------|-----|------|-----|---|---|
| M    | 1.69| 7.78| 32.35| 42.50| 6.59  | 5.55| 0.30 | 0.01| 0.21| 0.011|
| M2   | 2.07| 7.54| 31.91| 43.63| 6.52  | 5.92| 0.31 | 0.01| 0.16| 0.012|
| M4   | 2.11| 7.15| 31.45| 45.31| 6.38  | 5.42| 0.43 | 0.03| 0.18| 0.017|
| M6   | 1.93| 7.20| 31.37| 44.30| 7.46  | 5.26| 0.39 | 0.02| 0.23| 0.017|
| M8   | 2.00| 7.83| 31.19| 44.55| 7.35  | 3.68| 0.53 | 0.13| 0.11| 0.023|
| M10  | 1.12| 7.16| 30.60| 44.90| 6.48  | 3.10| 0.84 | 0.32| 0.14| 0.047|
| M21  | 2.34| 7.42| 31.97| 43.30| 6.59  | 5.56| 0.31 | 0.3 | 0.21| 0.014|
| M61  | 2.21| 6.95| 30.26| 45.55| 7.06  | 4.99| 0.33 | 0.13| 0.17| 0.017|
(b) Mass fraction of elements, %

| Flux | ZnO  | Cr₂O₃ | F   | BaO  | SrO  | TiO₂ |
|------|------|-------|-----|------|------|------|
| M    | 0.012| 0.04  | 0.37| -    | -    | 0.07 |
| M2   | 0.006| 0.10  | 0.45| 0.19 | 0.098| 0.08 |
| M4   | 0.008| 0.07  | 0.41| 0.38 | 0.20 | 0.09 |
| M6   | 0.008| 0.05  | 0.46| 0.34 | 0.19 | 0.09 |
| M8   | 0.005| 0.037 | 0.42| 0.64 | 0.39 | 0.12 |
| M10  | 0.013| 0.026 | 0.56| 1.52 | 0.58 | 0.16 |
| M21  | 0.004| 0.07  | 0.38| 0.34 | 0.20 | 0.07 |
| M61  | 0.011| 0.04  | 0.38| 0.64 | 0.39 | 0.11 |
| M81  | 0.004| 0.039 | 0.38| 0.83 | 0.41 | 0.11 |
| M101 | 0.003| 0.035 | 0.48| 1.03 | 0.54 | 0.14 |

Table 6. The chemical composition of the welded beads.

(a) Mass fraction of elements, %

| Flux | C  | Si   | Mn  | Cr  | Ni  | Cu  | V   | Mo |
|------|----|------|-----|-----|-----|-----|-----|----|
| M    | 0.07| 0.43 | 1.16| 0.05| 0.11| 0.14| 0.007| 0.021|
| M2   | 0.08| 0.26 | 0.83| 0.05| 0.13| 0.15| 0.003| 0.020|
| M4   | 0.07| 0.29 | 0.84| 0.05| 0.13| 0.15| 0.005| 0.020|
| M6   | 0.09| 0.26 | 0.77| 0.04| 0.10| 0.15| 0.004| 0.020|
| M8   | 0.04| 0.41 | 1.28| 0.05| 0.08| 0.13| 0.001| 0.01 |
| M10  | 0.04| 0.36 | 1.20| 0.05| 0.08| 0.12| 0.001| 0.01 |
| M21  | 0.09| 0.31 | 0.76| 0.05| 0.13| 0.15| 0.004| 0.019|
| M61  | 0.08| 0.23 | 0.77| 0.05| 0.13| 0.14| 0.004| 0.017|
| M81  | 0.05| 0.41 | 1.25| 0.04| 0.08| 0.13| 0.003| 0.01 |
| M101 | 0.04| 0.41 | 1.26| 0.04| 0.08| 0.13| 0.001| 0.01 |

(b) Mass fraction of elements, %

| Flux | Nb  | S    | P    | Ba   | Sr   |
|------|-----|------|------|------|------|
| M    | 0.003| 0.029| 0.018| otс. | otс. |
| M2   | 0.004| 0.026| 0.015| 0.0041| 0.0004|
| M4   | 0.003| 0.025| 0.014| 0.0054| 0.0006|
| M6   | 0.003| 0.021| 0.011| 0.0065| 0.0008|
| M8   | 0.012| 0.013| 0.011| 0.0096| 0.0010|
| M10  | 0.010| 0.014| 0.012| 0.0119| 0.0011|
| M21  | 0.002| 0.028| 0.016| 0.0049| 0.0001|
| M61  | 0.003| 0.026| 0.014| 0.0058| 0.0003|
| M81  | 0.011| 0.013| 0.011| 0.0086| 0.0005|
| M101 | 0.011| 0.012| 0.011| 0.0112| 0.0006|

The use of a strontium-barium modifier dust in the amount of 2-8% also reduces the level of contamination of the welded layer with non-metallic inclusions compared with the use of a larger amount of additive (10%).
Figure 1. The effect of the additive introduced into the deposited layer on the barium concentration.

Figure 2. The effect of the additive introduced into the deposited layer on the strontium concentration.

Figure 3. The effect of the additive introduced into the deposited layer on the sulfur concentration.

Figure 4. The effect of the additive introduced into the deposited layer on the phosphorus concentration.
Samples: a) M; b) M2; c) M4; d) M6; e) M8; f) M10; g) M21; h) M61; i) M81; j) M101.

**Figure 5.** Nonmetallic inclusions in the deposited layer.

**Table 7.** Characteristics of nonmetallic inclusions in the weld metal.

| Sample  | Non-metallic inclusions, point | nondeformable silicates | spot oxides | sulfides |
|---------|-------------------------------|-------------------------|-------------|----------|
| M       | 1b,2b, rare 3b                | la                      | la          |
| M2      | 1b,2b                         | la                      | -           |
| M4      | 1b,2b                         | la                      | -           |
| M6      | 1b,2b                         | la                      | -           |
| M8      | 1b,2b                         | la                      | -           |
| M10     | 1b,2b, rare 3b                | la                      | la          |
| M21     | 1b,2b                         | la                      | -           |
| M61     | 1b,2b                         | la                      | -           |
4. Conclusions

1) The possibility in principle of applying barium-strontium carbonatite as a refining and gas-
protective additive for welding fluxes is shown. The use of a mixture of barium-strontium carbonatite
with a liquid glass as an additive is more preferable with respect to the use of a dust additive.

2) It is determined that the use of barium-strontium additive in the amount not more than 8% is
optimal from the point of view of the contamination degree of the weld metal with nonmetallic
inclusions. This flux is recommended for welding and surfacing of mining equipment.

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