Development of a new wear-resistant flux cored wire for welding armor on the buckets of mining equipment

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Abstract. In the paper, the possibility of producing a flux-cored wire on the basis of the dust from gas purification of silicomanganese production and dust from a gas purification of aluminum production at a different ratio of components was studied. The possibility in principal of producing a flux-cored wire for surfacing is discussed, the qualitative indices are studied and the manganese recovery coefficients with various component ratios were calculated. Statistical processing of the obtained results was carried out, statistical dependences of the influence of the component composition on the deposited layer properties were constructed.

1. Introduction
In the process of mining equipment operation, a number of problems arise that lead to emergency stops. First and foremost, this is due to the operation of the main parts of mining equipment in the conditions of heavy wear, the working surfaces get destroyed, so, it requires the application of technological measures increasing their wear resistance. For this reason, the task of improving the technology of manufacturing new powder wires for mining equipment with high wear resistance becomes urgent. [1-12].

2. Methods of research
In the wear test, a method of mass loss of the sample was used, which is based on a change in the mass of the sample when performing a test disc-welding die. The wear of the samples was carried out on the machine 2070 CMT-1. The chemical composition of the weld samples was determined according to the state standards GOST 10543-98 by the X-ray fluorescence method on the XRF-1800 spectrometer and by the atomic-emission method using the DFS-71 spectrometer. The hardness of the welded layers was measured by hardness tester MET-DU. The evaluation of nonmetallic inclusions was carried out according to GOST 1778-70 on thin sections without etching by OLYMPUS GX-51 optical microscope with a magnification ×100.

3. Results and discussion
Wire manufacturing was carried out on a laboratory unit for the production of powder wires with passing it through drawing-blocks. The diameter of the produced wire was 6 mm, its cladding was made from St3 tape. The filler consisted of: dust from gas-purification system of aluminum production, wt. %: Al₂O₃ = 21-46.23; F = 18-27; Na₂O = 8-15; K₂O = 0.4-2.3; Si₂O = 0.5-2.48; Fe₂O₃ = 2.1-3.27; C = 12.5-30.2; MnO = 0.07-0.9; MgO = 0.06-0.9; S = 0.09-0.19; P = 0.1-0.18 and dust from silicone manganese gas-purification system, wt. %: Al₂O₃ = 2.43; Na₂O = 1.32;
K₂O = 5.56; CaO = 6.4; SiO₂ = 29.19; BaO = 0.137; MgO = 7.54; S = 0.23; P = 0.04; Fe = 1.067; Mn = 27.69; Zn = 2.687; Pb = 3.833.

Surfacing was carried out under a flux made of silicomanganese slag with chemical composition:

Table 1. Parameters of the flux cored wire.

| No | dust from silicomanganese gas-purification system at aluminum production | Total weight, g | Powder weight, g | Coefficient of filling, % | Manganese recovery, % |
|----|------------------------------------------------------------------------|----------------|----------------|--------------------------|----------------------|
| 81 | 100 g, 89.89 g, 11.25 g, 10.11 g, 19.759 g, 18.333 g, 1.426 g, 7.217 %, 73 |
| 82 | 100 g, 81.63 g, 22.5 g, 18.37 g, 17.816 g, 16.523 g, 1.293 g, 7.258 %, 82 |
| 83 | 100 g, 74.77 g, 33.75 g, 25.23 g, 18.975 g, 17.735 g, 1.240 g, 6.535 %, 88 |
| 84 | 100 g, 68.96 g, 45 g, 31.04 g, 19.510 g, 18.501 g, 1.009 g, 5.172 %, 126 |
| 85 | 100 g, 59.70 g, 67.5 g, 40.3 g, 19.089 g, 17.983 g, 1.106 g, 5.794 %, 124 |
| 86 | 100 g, 50 g, 100 g, 50 g, 19.428 g, 18.082 g, 1.346 g, 6.928 %, 124 |

Table 2. Chemical composition of the weld metal layer.

| Marking | Mass fraction of elements, % |
|---------|-----------------------------|
| C       | 0.08                        |
| Si      | 0.38                        |
| Mn      | 1.31                        |
| Cr      | 0.03                        |
| Ni      | 0.08                        |
| Cu      | 0.01                        |
| Ti      | 0.01                        |
| V       | 0.01                        |
| Mo      | 0.01                        |
| Al      | 0.01                        |
| Nb      | 0.01                        |
| S       | 0.01                        |
| P       | 0.01                        |

Table 3. Chemical composition of slag crusts.

| Marking | Mass fraction of elements, % |
|---------|-----------------------------|
| FeO     | 1.80                        |
| MnO     | 8.37                        |
| CaO     | 29.95                       |
| SiO₂    | 43.65                       |
| Al₂O₃   | 7.27                        |
| MgO     | 5.30                        |
| Na₂O    | 0.39                        |
| K₂O     | 0.16                        |
| S       | 0.17                        |
| P       | 0.10                        |
| ZnO     | 0.040                       |
| Cr₂O₃   | 0.048                       |
| TiO₂    | 0.63                        |

Table 4. Hardness and wear of samples.

| No | Initial weight, g | Weight after abrasion, g | Rotation, n | Loss of sample weight, g | Wear, g/rot. | Hardness, HB |
|----|-------------------|--------------------------|-------------|--------------------------|--------------|---------------|
| 81 | 82.587            | 82.139                   | 3070        | 0.448                    | 0.000016     | 126           |
| 82 | 92.395            | 91.960                   | 3300        | 0.435                    | 0.0000132    | 136           |
| 83 | 89.288            | 88.780                   | 4990        | 0.508                    | 0.0000102    | 132           |
| 84 | 84.935            | 84.495                   | 3500        | 0.44                     | 0.0000126    | 133           |
| 85 | 113.299           | 112.974                  | 3410        | 0.325                    | 0.0000095    | 143           |
| 86 | 115.758           | 115.338                  | 3300        | 0.42                     | 0.0000127    | 167           |
The error of the speed meter of the lower sample shaft is ± 3%, the limit for the permissible value of the random component mean square deviation of the friction torque meter reduced error in the static loading mode is – 1%. The tests were carried out in the following conditions: the load was 30 mA (78.4H), the frequency was 20 rpm, the samples loading was performed with a help of a spring mechanism, the rotation speed was measured by the tachogenerator on the motor shaft, and the number of rotations – by the non-contact sensor. During the test, the sample interacted with a block made of steel R18.

The studies shows that the manganese recovery factor (the ratio of the manganese concentration obtained in the weld metal to the total amount of manganese introduced) is associated not only with the reduction of manganese oxide from the manganese containing flux, due to the carbon contained in the flux cored wire, but also with a significant excess of carbon in flux cored wire made from manganese flux, with manganese recovery being more than 100% (table 1). The manganese recovery depends on the filling ratio of the flux-cored wire (figure 1), as well as on the concentration of carbonaceous material in the charge composition (dust from gas purification system of aluminum production) and, respectively, the carbon concentration in the weld metal (figures 2, 3).

Figure 1. Dependence of manganese recovery on the filling ratio of the flux cored wire.

Figure 2. Dependence of manganese recovery on concentration of dust from gas purification system of aluminum production.
Figure 3. Dependence of manganese recovery on the carbon concentration in the deposited metal.

Figure 4 shows non-metallic inclusions in the welded bead zone; the evaluation of nonmetallic inclusions, carried out in accordance with GOST 1778-70, is presented in table 5.

![Image](image_url)

Samples: a) 81; b) 82; c) 83; d) 84; e) 85; f) 86

Figure 4. Non-metallic inclusions in the welded zone of samples.

Table 5. Non-metallic inclusions in the zone of welded seams.

| Sample | Non-metallic inclusions, point |
|--------|-------------------------------|
|        | nondeformable silicates | spot oxides |
| 81     | 1b, 2b | 1a, 2a, 3a |
| 82     | 1b     | 1a, 2a, 3a |
| 83     | 2b, rare 4b | 1a, 2a |
| 84     | 2b, 1b | 1a |
4. Conclusions

1) The possibility in principal of producing a flux-cored wire for wear-resistant surfacing, using dust from gas purification system of silicomanganese and dust from gas purification system of aluminum production with a different components ratio is shown.

2) The optimal deposition modes were determined, qualitative indices were studied, and manganese recovery for various component ratios was calculated. Statistical processing of research results was carried out, statistical dependences of the influence of the component composition on the deposited layer properties were constructed.

3) This flux-cored wire is recommended for use.

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