A study on the properties of the deposited metal by flux cored wires 40GMFR and 40H3G2MF

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Abstract. The effect of chemical composition on the microstructure, hardness and wear resistance of the deposited layer of steels 40GMFR and 40H3G2MF was studied. The influence of the content of alloying elements in the examined steels on the structure of the deposited layer was defined, as well the influence of the structure of this layer on the hardness and abrasive wear. A comparative analysis of two steels was performed. Steel 40H3G2MF showed a greater efficacy for surfacing. It had higher hardness, a lower wear rate and a more fine-grained structure.

1. Introduction
Currently, to protect the hoppers and chutes used for transportation of mined rock and other abrasive materials, the fused wires are used corresponding to the systems C-Si-Mn-V-P and C-Si-Mn-Cr-Mo-V, which are represented by steels 40GMFR and 40H3G2MF [1-11].

2. Experimental research and results
The aim of this study was to investigate the influence of chemical composition on the wear resistance and hardness of the deposited layer. The wire was produced according to the known method [12-15] in the laboratory machine for manufacturing of flux cored wire (FCW). Diameter of the wire was 5 mm, the shell was made of steel strip St3. The respective powder materials were used as fillers, the carbon- and fluorine-containing dust of gas purification from aluminum production with the following chemical composition was used as carbon, mass %: Al2O3 = 21-46; F = 18-27; Na2O = 8-15; K2O = 0.4 – 6%; CaO = 0.7-2.3; SiO2 = 0.5-2.5; Fe2O3 = 2.1-3.3; Ctot = 12.5-30.2; MnO = 0.07-0.9; MgO = 0.06-0.9; S = 0.09-0.19; P = 0.10-0.18.

The surfacing by the produced wire was performed by submerged arc welding with flux AN-26S on the plate of steel St3. The chemical composition of the test samples was defined by X-ray fluorescence method on spectrometer XRF-1800 and atomic emission spectrometer DFS – 71. The chemical composition of the deposited layers is given in Table 1: samples No.1 – 4 are surfaced by wire from steel 40H3G2MF, samples No.5 – 7 by wire from steel 40GMFR. The surfacing was performed using the welding tractor ASAW-1250 at surfacing mode: I = 450 A, U = 30 V, V = 10 m/h. Wear resistance tests were conducted on device 2070 SMT – 1. Tests were carried out at the modes: load 30 mA, frequency 20 rot/ min. The samples hardness was measured with a hardness tester MET-DU.
Table 1. Chemical composition of the deposited layers.

| Sample No. | C    | Mn   | Si   | Cr   | V    | Mo  | Ni   | Co   | B   |
|-----------|------|------|------|------|------|-----|------|------|-----|
| 1         | 0.19 | 0.52 | 0.74 | 2.79 | 0.14 | 0.26| 0.17 | 0    | 0.001|
| 2         | 0.22 | 0.62 | 0.35 | 2.78 | 0.02 | 0.25| 0.09 | 0.04 | 0.001|
| 3         | 0.27 | 0.68 | 0.49 | 4.61 | 0.01 | 0.42| 0.36 | 0.03 | 0.001|
| 4         | 0.43 | 0.84 | 0.37 | 7.04 | 0.03 | 0.49| 0.42 | 0.06 | 0.001|
| 5         | 0.16 | 0.32 | 0.62 | 0.25 | 0.19 | 0.11| 0    | 0    | 0.003|
| 6         | 0.10 | 0.45 | 0.15 | 0.23 | 0.11 | 0.10| 0.08 | 0    | 0.003|
| 7         | 0.23 | 0.66 | 0.25 | 0.95 | 0.29 | 0.35| 0.34 | 0    | 0.003|

Metallographic studies of the microsections were performed using an optical microscope OLYMPUS GX-51 in the bright field magnifying in the range of ×100 - 1000 after etching in a 4% alcoholic solution of nitric acid. The fineness of the martensite structure was evaluated by comparing with the standards of the relevant scales and sizes of martensite needles in Table 6 of State Standards (GOST) 8233-56. Longitudinal study of samples of the deposited layer in the presence of non-metallic inclusions was carried out in accordance with GOST 1778-70 with magnification ×100. The grain size was determined in accordance with GOST 5639-82, magnification ×100.

Metallographic analysis showed that the structure of sample No.1 was a fine-needled martensite (point 3, 4) in the primary austenite grains (Figure 1a). Along the austenite grain boundaries the unclosed thin interlayers, presumably consisting of δ-ferrite, are located. The grain size of austenite on the gain scale corresponds to No.5 and No.4 (Table 2).

The examination of the nature of non-metallic inclusions of sample No.1 showed a significant degree of contamination, in particular with non-deformable silicates of points 5b and 4b and spot oxides of points 2a and 3a (Figure 2a).

As a result of the deposited layer investigation it is shown that its hardness is 44 HRC and the wear rate – 3·10⁻⁵ g/min (Table 3).

The structure of sample No.2 is fine-needle martensite (point 4) with zones of troostite inside the former austenite grains. The grain size of austenite corresponds to No.5 and 6 (Table 2).

The contamination degree of sample No.2 with nonmetallic inclusions is much lower compared to sample No.1. In sample No.2 non-deformable silicates are found, mainly of points 2a and 1b and rarely point 3a. Spot oxides are mainly of point 2a and rarely points 1a and 3a (Figure 2b). Thus, in this case a smaller amount of non-metallic inclusions are present, and they have a more dispersed structure.

However, the appearance of troostite in the structure is accompanied by a slight increase in the wear rate of the deposited layer to values 4·10⁻⁵ g/min and a decrease in its hardness to 36 HRC (Table 3).

Table 2. Characteristics of nonmetallic inclusions and samples structure.

| Sample No. | Contamination with non-metallic inclusions, point | Austenite grain size, point |
|------------|-----------------------------------------------|---------------------------|
|            | Non-deformable silicates | Spot oxides | Line oxides |                                      |
| 1          | 4 b, 5 b                     | 2 a, 3 a         | –          | 5, 4                                 |
| 2          | 2 a, 1 b, 3 a                | 2 a, 1a, 3 a     | –          | 5, 6                                 |
| 3          | 2 b, 3 b, 4 b               | 1 a, 2 a         | –          | 6, 7                                 |
| 4          | 1 a, 1 b                     | 1 a              | –          | 8, 7                                 |
| 5          | 3 b, 5 b                     | 1 a              | –          | 5, 6                                 |
| 6          | 1 a, 1 b, 2 b, 3 a          | 1 a              | –          | 5, 6                                 |
| 7          | 2 a, 3 b, 4 b               | 1 a, 2 a         | –          | 6, 7                                 |
Table 3. Results of the durability test.

| Sample No. | Sample weight at the beginning of test, g | Sample weight at the end of test, g | Loss of weight, (g/%) | Quantity of revolutions | Wear rate g/min | Hardness HRC |
|------------|------------------------------------------|----------------------------------|----------------------|------------------------|----------------|--------------|
| 1          | 132.768                                  | 132.573                          | 0.195/0.26           | 6214                   | 0.00003        | 44           |
| 2          | 185.2525                                 | 185.036                          | 0.216/0.117          | 4954                   | 0.00004        | 36           |
| 3          | 152.968                                  | 152.769                          | 0.199/0.13           | 4790                   | 0.00004        | 48           |
| 4          | 194.091                                  | 193.975                          | 0.116/0.06           | 4671                   | 0.00002        | 56           |
| 5          | 130.281                                  | 129.398                          | 0.883/1.15           | 5760                   | 0.00015        | 37           |
| 6          | 155.142                                  | 154.58                           | 0.562/0.36           | 5133                   | 0.00010        | 28           |
| 7          | 100.89                                   | 100.319                          | 0.571/0.56           | 4590                   | 0.00012        | 44           |

It is found that the increased content of carbon from 0.19 to 0.27% and manganese from 0.52 to 0.68% with the simultaneous significant increase of chromium, nickel and molybdenum (sample No.3) provides medium-needle (point 6) and coarse-needle (generally point 7 and rarely 8) martensite in the former austenite grains. The grain size of austenite in the structure of sample No.3 of grain size scale corresponds to No.6 and No.7 (Figure 1c, Table 2). Martensite is of the form of dark needles with regular boundaries; the martensite needle size is 6-19 µm. Along the primary austenite grain boundaries thin layers are located, consisting of δ-ferrite, intermetallics of σ-phase and dispersed carbides (Figure 1c).

Figure 1. Structure of steel samples 40H3G2MF (a – sample No.1; b – sample No.2. c – sample No.3; d – sample No.4).
The contamination degree with nonmetallic inclusions of sample No.3 is lower than of sample No.1. In this case there are non-deforming silicates of points 2b and 3b and rarely of points 4a and 4b, spot oxides are mainly of point 1a and rarely 2a (Figure 2a).

Increase in the carbon content and alloying elements in the deposited layer provides the austenite grain refinement as compared with sample No.1 No.2, and also leads to disperse carbides, increasing the hardness values up to 48 HRC, but practically does not influence on abrasive wear. The wear rate of sample No.3 is $4 \cdot 10^{-5}$ g/min (Table 3).
The chemical composition of the deposited layer of sample No.4 has a higher content of carbon and alloying elements in particular 7% of chromium. Metallographic analysis revealed that the primary austenite grain boundaries are clearly marked, fine-needle martensite is formed inside them (point No.3, 4). Between the austenite grains there are extended zones consisting of δ-ferrite, type intermetallics of σ-phase and dispersed carbides. In this case martensite has a more disperse structure (Figure 1 d).

The comparative analysis of the austenite gain size showed that among the rest examined samples welded with FCW made from steel 40H3G2MF sample No.4 has a smaller size of the primary austenite grain. The grain size of austenite in the structure of sample No.4 on a grain size scale corresponds to No.8 and No.7 (Table 2).

The contamination degree with non-metallic inclusions in sample No.4 is the lowest in comparison with other samples: there are non-deformable silicates of points 1a and 1b and spot oxides of point 1a (Figure 2 d, Table 2).

Formation of a fine-needle martensite structure and a significant reduction in the degree of contamination with non-metallic inclusions provides higher hardness values up to 56 HRC and reduces wear rate of the deposited layer to $2 \times 10^{-5}$ g/min compared to other samples of steel 40H3G2MF (Table 3).

The chemical composition of sample No.5-7 welded with steel 40GMFR is characterized by a lower carbon content (0.10-0.28%) and alloying elements than of samples No.1-4 welded with steel 40H3G2MF. As a result after welding a low carbon martensite is formed; this causes reduction in hardness and especially in wear resistance (Table 3).

Metallographic analysis showed that the structure of sample No.5 from steel 40GMFR, as well as sample No.1, contains fine-needle (point 4) martensite in the former austenite grains. Along its boundaries thin interlayers of δ-ferrite are located (Figure 3a). The austenite grain size on the graininess scale corresponds to No.5 and No.6 (Table 2).

Non-deformable silicates of points 3b and 5b and spot oxides of point 1a (Figure 2 d) are found in the result of contamination assessment of sample No.5 with nonmetallic inclusions.

Thus, the comparative analysis of samples No.1 and No.5 showed that the latter has a more fine-grained structure and is less contaminated with non-metallic inclusions. However, the structure characteristics of the deposited layer do not provide reduction in abrasive wear. The wear rate of the deposited layer in this case is considerably higher ($15 \times 10^{-5}$ g/min) compared with sample No.1 ($3 \times 10^{-5}$ g/min) (Table 3). Besides, the hardness of the deposited steel 40GMFR (sample No.5) is lower compared to steel 40H3G2MF (sample No.1).

It is found that the structure of sample No.6, with a higher content of manganese and lower quantity of other alloying elements in comparison with sample No.5, is a medium-needle martensite of...
points No. 5, 6 in the former austenite grains. The size of the martensite needles is 4-12 µm. There are thin interlayers of δ-ferrite (Figure 3b) along the austenite grain boundaries. Austenite grain size corresponds to No.5 and 6 (Table 2).

The contamination degree of sample No.6 with non-metallic inclusions is lower than of sample No.5. In this case non-deformable silicates of points 1a and 1b and rarely 2b, 3a and 3b, spot oxides of 1a point are detected (Figure 2f). Probably such characteristics of non-metallic inclusions influence the reduction of the wear rate of the deposited layer up to $10 \cdot 10^{-5}$ g/min, but also its hardness goes down to 28 HRC (Table 3).

![Figure 3](image-url)

**Figure 3.** Structure of the samples made from steel 40GMFR (a – sample No.5; b – sample No.6, c – sample No.7).

It has been established that a significant increase in the content of carbon, manganese, chromium, vanadium and molybdenum in the composition of the deposited steel provides a structure consisting of fine-needle (point 4) and medium-needle (point 5) martensite. The austenite grain size on the grain size scale corresponds to No. 6, 7 (Figure 3c).

The contamination degree of sample No.7 with nonmetallic inclusions, in particular with non-deformable silicates is lower in comparison with sample No.5: non-deformable silicates are found mainly of points 2b and 3b and rarely of point 4 b; spot oxides mainly of point 1a and rarely 2a (Figure 2 g).

This improvement of the structure decreases wear rate of the deposited layer to values $12 \cdot 10^{-5}$ g/min and increases its hardness values up to 44 HRC (Table 3).

The comparative analysis revealed that the size of the primary austenite grain in the structure of samples welded with FCW made from steel 40H3G2MF ranges from No.4 to No.8, and of samples welded by steel 40GMFR – from No.3 to No.7. The average hardness value of the deposited layer
from a more alloyed steel 40H3G2MF and wear rate is 46 HRC and 3·10⁻⁵ g/min. respectively for the samples surfaced by wire from steel 40GMFR – HRC and 10·10⁻⁵ 10 g/min.

Thus, it is shown that the samples surfaced by wire produced from wire of steel 40H3G2MF have a smaller austenite grain size, lower wear rate and higher values of hardness in comparison with the samples from steel 40GMFR.

3. Conclusions
Increase in the content of alloying elements in the surfaced steels 40H3G2MF and 40GMFR provides refinement of austenite grain, which is accompanied by the increase in the hardness of the deposited layer to values of 56 and 44 HRC respectively, and reduction in abrasive wear to a value of 2 and 10·10⁻⁵ g/min. respectively

For the surfacing of bunkers and trenches it is preferable to use FCW from steel 40H3G2MF in comparison to steel 40GMFR. The chosen welding technology provides a specific content and ratio of alloying elements in the steel, which forms a stable dispersed martensitic structure with a low volume fraction of δ-ferrite ensuring high hardness and resistance of the deposited metal to wear.

4. References
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