The influence of aging on the structure and properties of metal 30n8kh6m3styu obtained by surfacing

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Abstract. For surfacing wear-resistant coatings, flux-cored wires based on high-strength steels with the effect of secondary hardening are widely used. The aim of the work was to study the peculiarities of hardening by aging of economically alloyed steel 30N8Kh6M3STYu, obtained by welding wire with flux-cored wire. It has been established that such steel has the best results of durometric properties as a result of aging at a temperature of 550 ºС for 2 hours. In this case, the microhardness of the structural components increases 1.2-1.4 times, and the steel hardness reaches 53 HRC. It is shown that the structure of steel after aging consists of martensite and 14 types of compounds of phase components. It was established that steel hardening is due to the formation of complexes of four carbides TiD0.707C0.5, Cr3C2, TiC, SiC, nine intermetallic compounds Cr0.92Mo3.08, Fe0.875Mo0.125, D2Ti, Mo0.984Ni0.016, Ti3Al, Ni3Ti, FeCr, AlFe, NiTi2 and nitride Fe24N10. The rather high values of the hardness of such steel after aging and the insignificant effect of the duration of the effect of heat treatment on the reduction of its values allow us to recommend flux-cored wire created on its basis for surfacing parts operating under conditions of moderate wear at elevated temperatures.

1. Introduction

For the manufacture of critical parts, high-strength steels with the effect of secondary hardening have found wide distribution [1–5]. High-alloyed high-strength steels based on the Fe-Ni-Co-Mo system are best studied [3–5]. However, the high cost and scarcity of elements that ensure the hardening of the metal of this system limits its widespread use. The most important is the combination of high mechanical characteristics and performance properties with a minimum content of expensive and scarce alloying elements, which is achieved in economically alloyed steels.

2. Statement of a problem

The basis of many stainless economically alloyed dispersion-hardening steels is the system Fe-Ni-Cr [1, 2, 6]. To obtain a martensitic matrix, such steels should contain 6–12% Ni and 6–8% Cr. In steels with a nickel and chromium content at the lower limit, it is advisable to use carbon to reduce the temperature of the onset of martensitic transformation and harden martensite after quenching [5–7]. Its concentration can reach up to 0.3%. In this case, it becomes possible to use carbide intermetallic hardening. For intermetallic hardening of such a matrix, molybdenum, titanium and aluminum are used [1, 2, 6–9]. This served as the basis for the development of the group of dispersion-hardening steels of the system Fe-C-Ni-Cr-Mo-Ti-Al [1, 2, 6]. Significant disadvantages of such steels include their low wear resistance [6]. As a result, they can be used for the manufacture of parts operating in conditions of moderate wear. Therefore, an urgent task is to increase the wear resistance of the steel of such a system.

To increase the degree of hardening of the steel of the system under study and, as a consequence
of wear resistance, it is possible to additionally alloy it with silicon [5, 6, 10–12]. Silicon significantly affects the decrease in solubility in martensite of molybdenum, titanium and aluminum, forming reinforcing particles. The enhancement of the hardening effect is achieved when it is introduced into the steel up to 2.5–3% [5, 10]. In this regard, one of the most promising dispersion-hardening compositions can be steel 30N8Kh6M3STYu, which could be used for surface wear-resistant coatings with cored wire created on its basis. However, the features of the hardening by aging of such steel obtained by surfacing have not been studied.

In this regard, the aim of the work is to study the effect of aging on the structure and properties of cast steel of the Fe-C-Ni-Cr-Mo-Ti-Al system.

3. Objects and methods of research
The object of research was the metal coating deposited with cored wire created on the basis of steel 30N8Kh6M3STYu. To ensure the required carbon content in steel, high-carbon FeCr was introduced into the flux-cored wire. The calculated composition of the experimental flux-cored wire is given in Table 1.

Table 1. Design structure of experimental powder wire, %

| Ni  | FeCr | Mo  | FeSi | FeTi | FeAl | Na2SiF6 | Fe  | Fe – tape |
|-----|------|-----|------|------|------|--------|-----|---------|
| 8.5 | 8.0  | 3.5 | 2.6  | 5.2  | 1.8  | 0.3    | 16.5| rest    |

Metal samples for research were obtained by surfacing rollers of coatings in argon on plates made of St3 steel measuring 200×50×10 mm using experimental cored wire of 2.4 mm diameter in 3 layers.

Hardening by heat treatment was carried out on modes that include heating the weld metal to a temperature of 550 °C [13] and holding for 2, 6 and 10 h.

Metallographic studies of the weld metal were carried out on an Axio Observer A1m optical microscope (Carl Zeiss). The microstructure was detected by chemical etching in the reagent composition: CuSO4 – 4 g; HCl – 20 ml; H2O – 20 ml.

Analysis of the effect of heat treatment on the hardening of the metal was carried out according to the results of measuring the hardness over the cross section of the weld coating.

Durometric studies were performed on metal samples after surfacing and aging. The hardness of the weld metal was measured by the Rockwell method on a TK-2 instrument. The microhardness of the structural components of the weld metal was determined by the Vickers method on a Shimadzu HMV-2 microhardness meter with loads of 10 g, 25 g and 50 g.

The carbon content in the metal under study was determined by infrared spectroscopy by burning a sample at a temperature of 1350 °C in an oxygen atmosphere using a METAVAK -CS30 analyzer. Metal shavings weighing 500–650 mg were used as samples, the accuracy of carbon detection was 0.001%. The nitrogen content in the metal under study was determined by melting the sample at a temperature of 2500 °C in a helium atmosphere using a METAVAK-AK analyzer. As a sample, a piece of metal weighing 400–450 mg was used, the accuracy of nitrogen determination was 0.0001%.

X-ray phase analysis was performed on a Shimadzu XRD-7000 multifunctional X-ray diffractometer. The surveys were carried out in filtered copper Kα – radiation with an operating mode of an x-ray tube of 40 kV and 40 mA. For survey surveys, the scan rate was 0.2 ° / min with a scintillation detector movement increment of 0.05°. Precision studies were carried out with the same detector pitch and exposure at a point up to 15 sec. at given angles of Bragg diffraction. The average value of the radiation wavelength fixed by the detector is \( \lambda = 1,5406 \) Å. The dimensions of the irradiated area on the sample were \( 2 \times 5 \) mm. Samples were taken at room temperature in the range of Bragg diffraction angles of \( 2 \cdot \theta = 20...130° \). For processing and analyzing the diffraction spectra applied the software package Match! version 3.7.0.124.
4. Results of the experiments and discussion

A chemical analysis showed that the metal under study 30N8Kh6M3STYu, which was obtained by surfacing with experimental cored wire, contains 0.3238% carbon, 0.0093% nitrogen and 0.01556% sulfur.

It is established that the hardness of such a metal after surfacing is in the range of 45–47 HRC.

The distribution of hardness over the cross section of the metal of the coating of the investigated composition after surfacing and aging is shown in Fig. 1.

Aging at a temperature of 550 °С affects the hardening of the weld metal. The values of the hardness of the metal after aging for 2 hours are in the range of 51.5–53.5 HRC. As a result, in the range of 51–53 HRC. After aging for 10 hours, the average hardness values slightly decrease to 49–51 HRC.

The data obtained led to the research of the metal after surfacing and the metal that passed aging under the regime at a temperature of 550 °C for 2 hours, which showed the best results.

The results of the study of the microhardness of the structural components of the metal 30N8Kh6M3STYu, the microstructure of which is shown in Fig. 2, after surfacing are summarized in Table 2.
As can be seen, the microhardness of the metal matrix after surfacing is low and amounts to 492–503 HV, and the hardening phases are 668–732 HV. There is a slight amount of eutectic discharge with a hardness of 526–571 HV.

The results of the study of the microhardness of the structural components of the metal 30N8Kh6M3STYu, the microstructure of which is shown in Fig. 3, after aging 550 ºC are summarized in Table 3.

After aging, the microhardness distribution pattern has changed. The microhardness of the
matrix has increased 1.3 times and is in the range of 639-683 HV, strengthening phases in 1.2 times and is in the range of 783-882 HV. The amount of eutectic discharge has increased, and their microhardness is in the range of 650-786 HV, which is 1.2-1.4 times higher than after surfacing. Thus, the microhardness of the structural components of the metal after aging increases.

To identify the mechanism of hardening of the metal under investigation, X-ray structural studies were performed.

The results of X-ray phase analysis of the metal of composition 30N8Kh6M3STYu after surfacing are shown in Fig. 4. The results of decoding the diffraction pattern of the metal are summarized in Table 4.

It has been established that the basis of the metal matrix after surfacing is martensite. The structure includes 6 types of compounds of phase components. It contains a significant amount of Fe₃C₂ iron carbide, intermetallic compounds for the most part are Fe₂Ti, Fe₇Mo₆, Mo₀.₉₈Nᵢ₀.₀₁₆, Fe₅Si₃, and a small amount of Si₂Ti.

![Figure 4. Diffractogram of metal coating after surfacing](image)

Table 4. Decoding diffractogramme of metal coating after surfacing

| №  | Phase name and card number | Int. peaks | Lattice Type | Lattice parameters tabular | Lattice parameters calculated |
|----|----------------------------|------------|--------------|----------------------------|-------------------------------|
| 1  | Cr₀.₇Fe₀.₃ (96-152-4270)   | V.S.       | cubic        | a = 2.8720 Å               | a = 2.87614 ± 0.00024 Å     |
| 2  | Cr₀.₈Ni₀.₂ (96-152-5377)   | V.S.       | cubic        | a = 2.8730 Å               | a = 2.87614 ± 0.00024 Å     |
| 3  | α-Fe (96-110-0109)         | V.S.       | cubic        | a = 2.8680 Å               | a = 2.87614 ± 0.00024 Å     |
| 4  | Fe₃C₂ (96-152-1832)        | S.         | monoclinic   | a = 11.5880 Å              | a = 11.60801 ± 0.00636 Å    |
|    |                            |            |              | b = 4.5790 Å               | b = 4.56956 ± 0.00170 Å     |
|    |                            |            |              | c = 5.0590 Å               | c = 5.02911 ± 0.00457 Å     |
|    |                            |            |              | β = 97.746 °               | β = 97.31795 ± 0.06830 °    |
| 5  | Fe₂Ti (96-152-3307)        | A.         | hexagonal    | a = 4.7850 Å               | a = 4.77654 ± 0.00070 Å     |
|    |                            |            | trigonal     | c = 7.7990 Å               | c = 7.80047 ± 0.00185 Å     |
| 6  | Fe₅Mo₆ (96-150-1464)       | A.         | hexagonal    | a = 4.7402 Å               | a = 4.71600 ± 0.00065 Å     |
|    |                            |            | axes         | c = 26.0028 Å              | c = 26.21827 ± 0.00636 Å    |
The results of X-ray phase analysis of the metal of composition 30N8Kh6M3STYu after aging are shown in Fig. 5. The results of the interpretation of the diffraction pattern of the metal are summarized in Table 5.

![Diffractogram of metal coating after aging](image)

**Table 5. Decoding diffractogramme of metal coating after aging**

| №  | Phase name and card number         | Int. peaks | Lattice Type          | Lattice parameters tabular | Calculated               |
|----|------------------------------------|------------|-----------------------|---------------------------|-------------------------|
| 1  | Fe (96-901-3474)                   | S.         | cubic                 | a = 2.8730 Å              |                         |
| 2  | Fe$_{0.63}$Si$_{0.27}$Cr$_{0.1}$ (96-152-4429) | A.         | cubic                 | a = 2.8720 Å              | a = 2.8720 ± 0.00047 Å  |
| 3  | FeNiAl (96-900-8803)               | S.         | cubic                 | a = 2.8810 Å              | a = 2.8810 ± 0.00047 Å  |
| 4  | Cr$_{0.8}$Ni$_{0.2}$ (96-152-5377) | A.         | cubic                 | a = 2.8730 Å              | a = 2.8730 Å            |
| 5  | TiD$_{0.707}$C$_{0.3}$ (96-153-2051) | S.         | trigonal (hexagonal axes) | a = 3.0821 Å              | a = 3.07773 ± 0.00059 Å |
|    |                                    |            |                       |                          | c = 5.0405 Å            | c = 5.03926 ± 0.00174 Å |
| 6  | Cr$_{2}$C$_{2}$ (96-591-0109)      | A.         | orthorhombic          | a = 2.8200 Å              | a = 2.8200 ± 0.00079 Å  |
|    |                                    |            |                       | b = 5.5200 Å             | b = 5.5401 ± 0.00435 Å  |
|    |                                    |            |                       | c = 11.4600 Å            | c = 11.46957 ± 0.00225 Å|
| 7  | Cr$_{0.2}$Mo$_{0.8}$ (96-153-8537) | A.         | trigonal (hexagonal axes) | a = 2.9820 Å              | a = 2.97977 ± 0.00108 Å |
|    |                                    |            |                       | c = 28.8100 Å            | c = 28.88220 ± 0.03635 Å|
| 8  | Fe$_{2}$N$_{10}$ (96-231-0872)     | A.         | trigonal (hexagonal axes) | a = 9.2150 Å              | a = 9.20288 ± 0.00249 Å |
|    |                                    |            |                       | c = 4.3440 Å             | c = 4.35438 ± 0.00133 Å |
| 9  | Fe$_{0.875}$Mo$_{0.125}$ (96-231-0291) | A.         | cubic                 | a = 2.9099 Å              | a = 2.9099 ± 0.00037 Å  |
|    |                                    |            |                       | c = 3.1930 Å             | c = 3.19305 ± 0.00062 Å|
| 10 | D$_{2}$Ti (96-231-0985)            | A.         | tetragonal            | a = 4.2670 Å              | a = 4.26459 ± 0.00121 Å |
|    |                                    |            |                       | c = 4.2670 Å             | c = 4.26459 ± 0.00121 Å|

V.S. – very strong; S. – strong; A. – average; W. – weak
Mo_{0.984}Ni_{0.016} (96-152-3377) W. cubic $a = 3.1441 \pm 0.00044 \text{ Å}$

Ti_{3}Al (96-153-2768) W. hexagonal $a = 5.77640 \pm 0.00122 \text{ Å}$ $c = 4.6640 \pm 0.00112 \text{ Å}$

Ni_{3}Ti (96-101-0453) W. hexagonal $a = 5.0960 \pm 0.00078 \text{ Å}$ $c = 8.31255 \pm 0.00195 \text{ Å}$

TiC (96-153-9506) W. cubic $a = 4.3500 \pm 0.00107 \text{ Å}$

FeCr (96-152-4008) V.W. cubic $a = 2.90030 \pm 0.00037 \text{ Å}$

AlFe (96-154-1194) V.W. cubic $a = 2.9100 \pm 0.00056 \text{ Å}$

NiTi_{2} (96-152-7849) V.W. cubic $a = 11.3193 \pm 0.00107 \text{ Å}$ $c = 11.30994 \pm 0.00232 \text{ Å}$

SiC (96-101-1032) V.W. cubic $a = 4.35876 \pm 0.00063 \text{ Å}$ $c = 4.35876 \pm 0.00063 \text{ Å}$

D – elements of transition metals, taking into account the chemical composition of steel Cr, Fe, Ni, Mo
V.S. – very strong; S. – strong; A. – average; W. – weak; V.W. – very weak

The basis of the metal matrix after aging is also martensite. However, the structure already includes 14 types of compounds of phase components. It contains particles of carbides, for the most part TiD_{0.707}C_{0.5}, and a very small amount of TiC, SiC. Another group of compounds are intermetallic compounds. These are mostly Cr_{0.92}Mo_{3.08}, Fe_{0.875}Mo_{0.125}, D_{3}Ti, as well as a small amount of Mo_{0.984}Ni_{0.016}, Ti_{3}Al, Ni_{3}Ti, and a very small amount of FeCr, AlFe, NiTi_{2}. In the structure, small amounts of Fe_{3}N_{10} nitride are observed.

The results show that the transformation of the 30N8Kh6M3STYu metal as a result of aging is characterized by the appearance of four carbides with the participation of Fe, Cr, Ti, Si, Mo, Ni, nine intermetallic phases with the participation of Fe, Cr, Mo, Ti, Ni, Al, and iron nitride Fe_{24}N_{10}, instead of iron carbide Fe_{5}C_{2} and five intermetallic phases with the participation of Fe, Ti, Mo, Ni, Si in the metal structure after surfacing.

5. Conclusion
1. It has been established that the best results of the durometric properties of 30N8Kh6M3STYu steel are achieved as a result of aging at a temperature of 550 °C for 2 hours. In this case, the microhardness of the structural components increases 1.2-1.4 times, and the steel hardness reaches 53 HRC.

2. It is shown that the dispersion hardening of steel 30N8Kh6M3STYu as a result of aging is due to the formation of complexes of four carbides dominating in the structure with different ratios of six elements Fe, Cr, Ti, Si, Mo, Ni, nine intermetallides with different ratios of six elements Fe, Cr, Mo, Ti, Ni, Al and one nitride of Fe_{24}N_{10}.

3. The rather high values of hardness of steel 30N8Kh6M3STYu after aging and a slight effect of the duration of the effect of heat treatment on reducing its values allow us to recommend flux-cored wire created on its basis for surfacing parts operating under conditions of moderate wear at elevated temperatures.

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