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ENGINEERING AND RESEARCH OF WEARABILITY COATING ON THE BASIS OF HIGH-STRENGTH STEEL

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Abstract: Methods of the optical metallography, TEM, SEM- technique, X-ray analysis, tests for hardness and wear resistance, are resulted results of research and optimization of structure and properties facing materials with austenite-martensite structure and with various quantity of strengthening phases. The maintenance in facing material austenite 38% is shown, that, martensite 32% and strengthening phases of 30% provide the highest relative wear resistance $\varepsilon = 5.89$ and hardness HRC 61.

Keywords: X-ray analysis, optical and electronic microscopy; microhardness, high-strength steel.

1. INTRODUCTION

Applying coating using arc welding increases of resistance to abrasive outwearing on working surfaces of machine parts from high-carbon alloys based on iron, by composition similar to tool steels [1–8].

The purpose of the given work was research of mechanical properties and structures of overlaying welding metal after various technological modes of drawing of covering, and development of structural – phase model of increase of wear resistance of overlaying welding's materials.

2. METHODOLOGY

Structural and phase changes occurring in samples of welding materials by optical microscopic metallography, transmission electron microscopy (TEM) and scanning electron microscopy (SEM), X-ray diffractometry, and macro- and microhardness tests were studied.

The surfacing was carried out on steel 45 by arc welding. In the process of welding alloying elements with various coefficients of transition got in overlaying welding metal. The structural and phase composition of the materials depended on this process. From the received overlaying welding's standard samples were produced (see Table 1) for abrasive wear testing.

Table 1. The contents of alloying elements (AE), % in the investigated overlaying welding's.

Numbers overlaying welding's								
AE, %	1	4	3	7	2	6	5	8
C	0.8	1.7	0.9	0.8	1.8	1.5	0.8	1.6
Si	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Cr	7.1	6.3	6.6	9.6	6.7	10.4	10	10.3
Mo	7.8	7.3	4.4	4.3	4.4	4.5	7.6	7.7
Nb	2.0	0.4	2.2	0.4	0.5	1.8	0.5	2.4
Mn	0.7	0.7	0.9	0.7	0.8	0.8	0.5	0.9
V	2.7	1.0	1.1	1.6	2.6	1.1	1.2	2.7
B	0.05	0.05	0.25	0.05	0.25	0.05	0.25	0.32
Σ AE	21.8	18.1	16.8	18.1	17.5	20.8	21.3	26.3

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For comparison, surfacing with ferrite-pearlite and austenite-martensite structures were investigated. They were applied to steel 45 by means of automatic arc welding with electrode tape under fluxes.

X-ray diffraction analysis was used for research of structure and phase changes occurring in samples of overlaying weldings materials. Transmission electron microscopy (TEM) [9] and method of one-step coal films are used to study morphology and disposition of phases in structure of overlaying weldings materials.

3. RESULTS AND DISCUSSION

3.1. Results of Mechanical Tests.

The relative wear resistance of materials (the standard was steel 45) were changed from 0.63 to 5.89. The resulting structures had grains size Dg = 10...50 μm, with hardness of materials 26…61 HRC and microhardness H_{50}(3600…12500) MPa. The samples are placed in order of increasing their relative wear resistance (ε) in Table 2 and in Fig. 1, 2.

Table 2. Properties of researched materials of surfacing.

Welding number	Properties of materials of surfacing			
	Grain size Dg, μm	Macrohardness, HRC	Microhardness, MPa, H_{50}	Relative wear resistance, ε
1	16	27.5	3600	0.63
4	50	50	10640	1.18
7	50	47	12140	1.43
3	30	60	8440	1.88
6	40	33.5	7450	3.30
5	30	55	12500	3.44
2	15	58	7740	3.66
8	10	61	7540	5.89

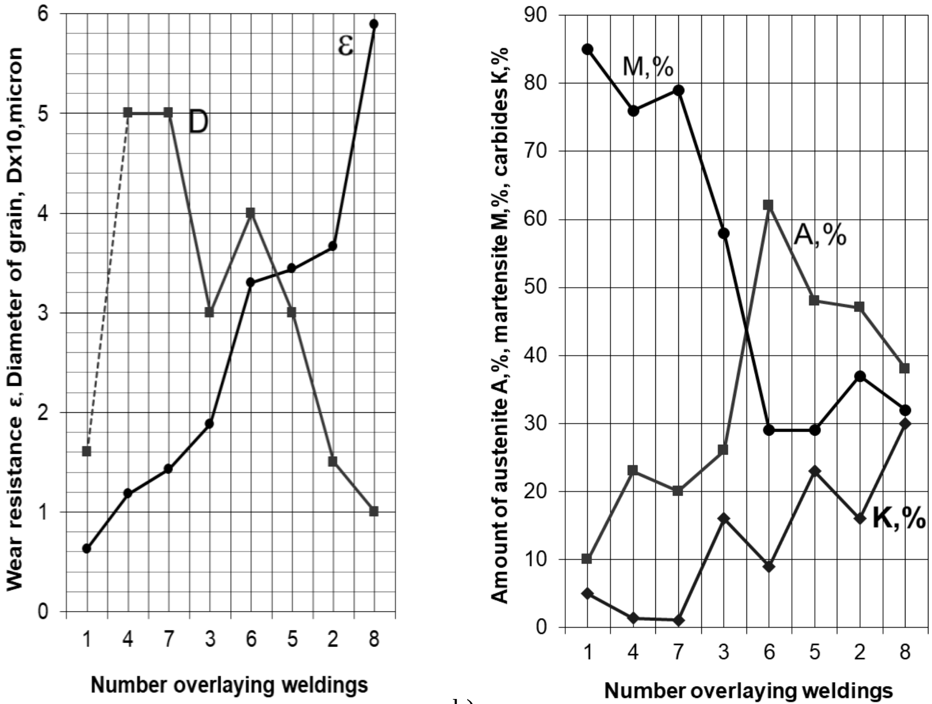
Resistance to wear of samples increased non-uniformly stepped – № 1, 4, 7, 3 (I stage), № 6, 5, 2 (II stage), № 8 (III stage).

3.2. X-ray Diffraction Research

We used X-ray analysis through Rotaflex diffractometer to find the phase composition of welding metal. Martensite and residual austenite were the main phases in all coatings. Carbides (MeC, Me_2C, Me_7C_3, $Me_{23}C_6$), borides (MeB, MeB_2), carbo-borides Me_7BC_4, intermetallic compounds on basis Fe and oxides were found in samples.

Relative wear resistance of overlaying welding's increased when the size of the primary austenite grains (Dg) decreased. (see Fig. 1) This provided hardening of the surfacing materials on grain boundaries. With increasing in the amount of austenite and strengthening phases and decreasing in martensite, the materials relative wear resistance increases. At the same time, the maximum wear resistance of materials is achieved with approximately equal content of martensite, austenite and hardening phase.

The relative wear resistance of the surfacing materials increased as the number of strengthening phases (K) increased, which provided the dispersion hardening of the surfacing materials (Fig. 1 b) With an increase in the number of reinforcing phases (K), the relative wear resistance of materials increased. This ensured the dispersion hardening of the materials. Wear resistance of surfacing materials increases due to an increase in hardness, dispersion and hardening along the grain boundaries of the material. Wear decreases by increasing the concentration of carbide-forming elements in the solid solution and by increasing in the number of carbides and carbide-containing phases. It is also associated with an increase in strength and plastic properties because of reduction of grain sizes. The optimal proportion in the surfacing material is next: martensite 30…40%, austenite 35…40%, and hardening phases 25…30%. It provided the attainment of the maximum relative wear resistance ε = 5.89 and the hardness HRC 61 of the surfacing materials.



a) b)

Figure 1. Dependence of the grain diameter (Dg) (a), the amount of martensite (M) (b), austenite (A) (b) and strengthening phases (K) (b) on the relative wear resistance (ε) (a) and weld deposition number (N).

3.3. Optical Microscopic Metallography and Electron Microscopy Research

We used optical microscopic metallography and electron microscopy for the analysis of morphology and disposition of phases in structure of materials (Fig. 2).

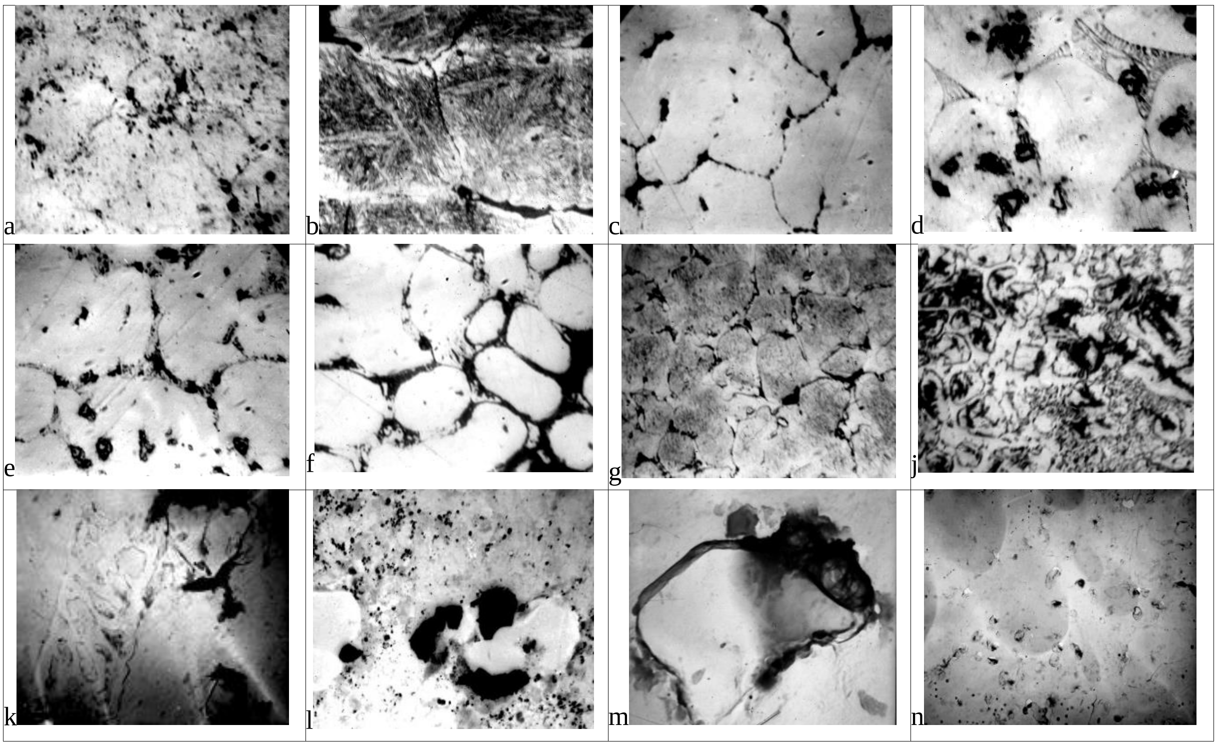


Figure 2. The structure of the investigated numbers of surfacing (№) 1 (a), 4 (b), 7 (c), 3 (d), 6 (e), 5 (f), 2 (g), 8 (j) as their wear resistance increases ε. ×1000. Electron-microscopic images of hardening phases in the investigated surfacing: NbC (k), (Cr, Fe)$_7$C$_3$ (l), CrB (m), V$_2$C (n). ×9000.

Wear of the upper welds layers decreases, the number of secondary phases increases in the grain, and the composition becomes more complex.

Sample №1 had the lowest wear resistance ($\varepsilon = 0.63$). There was ferrite-carbide structure without austenite. Particles of hardening phases were fractured from martensite bases (fig. 2 a). In samples № 4, 3, 7 ($\varepsilon = 1.18…1.88$) islets of austenite were formed at the boundaries of the martensite grains. They were stuck and did not fracture. Particles of the CrB and CrB_2 (Fig. 2 b, d, m) contributed to this due to their large sizes and complex forms. Samples № 2, 6, 5 had $\varepsilon = 3.30…3.66$. The residual austenite is present here in the form of grains ringing. Particles $(Cr, Fe)_7C_3$, NbC strongly keeps by austenite with high viscous – plastic properties and this increases wear resistance. Additional strengthening carbides (Me_2C) are allocated on borders and in the body of grains. (Fig. 2 e–g). The abrasive austenite can undergo in full or in part transformation in martensite during friction, that should result in additional increase of wear resistance of overlaying welding materials. Martensite can, in the friction process completely or partially transform into austenite of friction, which should lead to an additional increase in the wear resistance of the welding materials. Sample № 8 ($\varepsilon = 5.89$), had martensite structure, bordered by austenite with small grains. It includes a lot of carbides, borides, carbo-borides and intermetallic compounds. (Fig. 2 j).

Thus, the wear resistance of surfacing materials increases with an increase in amount, hardness and particle sizes of the strengthening phases. Also optimal morphology of the allocation of carbides and carbide-containing phases formed in structure of grains. Martensite structure with grains (sizes 10…15 μm) strenged with dispersed carbides and covered with austenite rim had optimal properties. Most of the carbides and borides of chromium, niobium and vanadium were located in soft austenite rim.

In the study of surfacing with ferrite-pearlite and austenite-martensite structures by means of transmission electron microscopy, it was found that grains of structurally-free ferrite were present in the base metal of steel 45 with microhardness of 4500 MPa. There were perlite colonies with sizes 5–15 μm with the distance between the plates 0.08–0.14 μm, and microhardness of 5000 MPa. (Fig. 3 a) Near the fusion line on the side of the base metal, there were extinction circuits, caused by the action of thermal stress fields.(Fig. 3 b) The minimum dislocation density values of $2{\cdot}10^{10}\,cm^{-2}$ were achieved there. There was dissolution of cementite plates, and microhardness of ferrite increased to 5700 MPa. The upper bainite was formed. In the structure of the 2nd surfacing layer at distance of 3 mm from the fusion line, considerable softening of ferrite to 2800 MPa and perlite to 3300 MPa was observed. This indicated significant relaxation of internal stresses. The dissociation of large cementite particles and the formation of secondary small cementite particles along the boundaries of the cells, fragments were observed. (Fig. 3 c, d). In the structure of the 4th surface layer, repeated hardening of the material was achieved due to the formation of small dislocation subgrains structure with cell size of 0.5–0.8 μm. Here, the maximum values of dislocation density were $10{\cdot}10^{10}\,cm^{-2}$ and microhardness increased for ferrite to 3300 MPa and for perlite to 4300 MPa. In both cases, regular structure was formed with martensite structure or perlite structure, surrounded with soft austenite or ferrite phase, respectively. However, the tribological tests of the welded material with ferrite – perlite structure compared with steel 45 showed small relative wear resistance ($\varepsilon = 0.5$). The surfacing materials with austenite – martensite structure showed relative wear resistance ($\varepsilon = 1.5$).

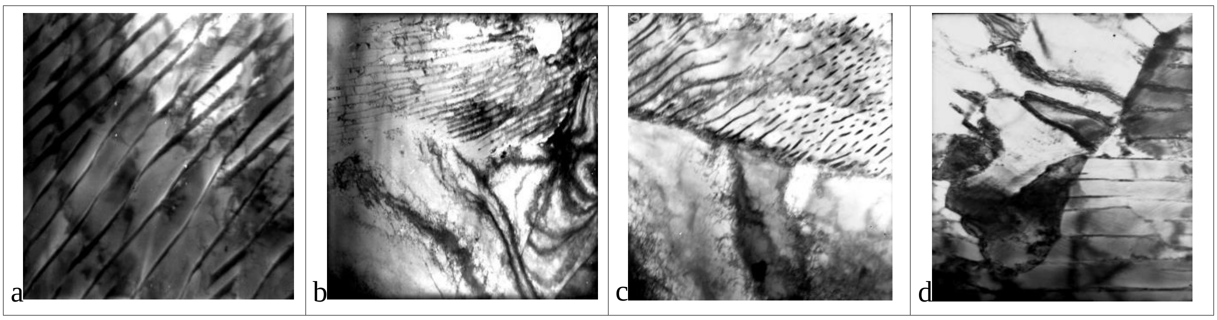


Figure 3. Electron-microscopic images of the structure of ferrite-pearlite and austenite-martensite surfacing, ×10000–39000.

4. CONCLUSIONS

Scheme of the structural-phase state of all surfacing materials was developed as their wear resistance increased, depending on the size of the grains, the amount of carbides and carbide-containing phases, and also the morphology of their distribution (Fig. 4).

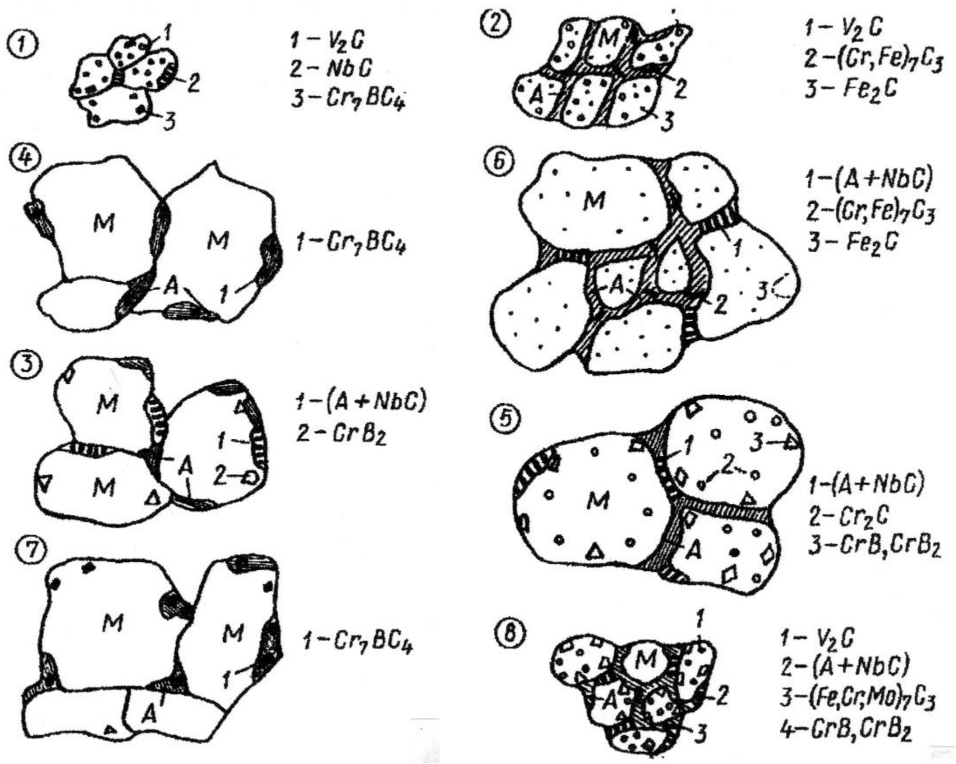


Figure 4. Circuits of a structural – phase status of the investigated materials. Figures in circles – numbers overlaying weldings.

Thus, wear resistance of overlaying welding metal depends on many factors: hardness, matrix strength, shape and allocation of strengthening phases, forces of interaction of matrix with the particles, hardening alloys [10–14].

The resistance to wear is determined by the quantitative and qualitative structural and phase state of overlaying welding's. High wear resistance corresponds to the following structure: small grains with martensite structure strengthened by dispersed carbides of the M_2C type, edged with plastic austenite, which contains carbide phase.

Structural-phase transformations in the volume of multilayer surfacing materials with austenite-martensitic structure designed for blades of mixers have been studied. With the help of transmission electron microscopy, regular changes in the structural-phase state and material properties occured in various layers of the coating with ferrite-pearlite structure. Near the fusion line on the side of the base metal, large internal thermal stresses were formed in the structure of the upper bainite. There maximum hardness and supersaturation of the alloying elements were achieved. In the second layer of surfacing, the maximum softening of the material was observed, all signs of the heat-affected zone were present, as in the main metal during welding. In the fourth surface layer, the material was strengthened again, due to the formation of the lower bainite and the dislocation subgrain structure. High wear resistance of surfacing materials with austenite-martensite structure obtained under flux is explained by the presence of solid martensite matrix with residual austenite. Austenite surrounds the grains with martensite structure and firmly holds the particles of the second phase. This surfacing material can be recommended for manufacturing blades of mixers.

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