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Influence of structure and phase composition on wear resistance of sparingly alloyed alloys

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The paper is concerned with the influence of wear on the formation of a "white stripe" in metastable austenitic, austenomartensitic and secondary hardening steels of the Cr–Mn–Ti system additionally alloyed with Mo, B, V. It was shown that the conducted studies confirm the possibility of the formation of a "white stripe" both in alloys having a high concentration of austenizing elements (Mn, C, Ni) and in materials alloyed with carbide-forming elements with a relatively low affinity to carbon (V, Mo).
Keywords: steel, secondary hardening steels, alloying system, wear resistance, white stripe.

Вплив структури та фазового складу на зносостійкість економнолегованих сплавів. *Д.Б.Глушкова, В.А.Багров, В.М.Волчук, У.А.Мурзахметова*

У статті розглянуто питання впливу зносу на утворення "білої смуги" в метастабільних аустенітних, мартенситноаустенітних і вториннотвердіючих сталях системи Cr–Mn–Ti додатково леговані Mo, B, V. Показано, що проведені дослідження підтверджують можливість утворення "білої смуги" як у сплавах, що мають високу концентрацію елементів — аустенізаторів (Mn, C, Ni), так і при легуванні карбідоутворюючими елементами з відносно невисокою спорідненістю до вуглецю (V, Mo).

1. Introduction

The use of advanced technological operations makes it possible to set the desired structure and properties of the materials under study by nanomodifying them [1], increase the corrosion resistance of welded joints, control the structure and properties of powder gas-plasma coatings [2], increase the corrosion resistance of heat-resistant alloys for power equipment parts [3]. At the same time, the use of mathematical methods allows to optimize the processing modes of critical importance products, which positively affects their service characteristics [4].

Studies aimed at developing improvements for sparingly alloyed wear-resistant steels for depositing of material on tools for hot metal processing is very relevant.

The hot metal processing tool is intended to perform the main operation — plastic deformation of metal at high temperatures. For high efficiency of work, this tool must have sufficient hardness, resistance to compression, bending, dynamic loads, high resistance to abrasion and impact-abrasive wear, heat resistance, and have a well-treated surface of the working parts.

This paper describes the study of the influence of structure and phase composition on wear resistance of sparingly alloyed metastable and secondary hardening steels.

2. Material and methods

The depositing of the studied materials was carried out using copper molds with different rates of forced cooling. Metastable austenitic, austenomartensitic and secondary hardening steels of the Cr–Mn–Ti system additionally alloyed with Mo, B, V were studied.

Wear tests were carried out in accordance with the requirements of the State Standard 30480-97 "Ensuring of wear resistance of products. Methods assays wear resistance. Principles of provision. General".

The test was conducted using a friction machine 2070 CMT-1, with a disc-pad as the test configuration. Friction modes: disc rotation speed 0.5 m/s; sample load 25, 50 N; counterbody material — steel 45X, HRC 47...49.

The wear of the deposited metal under conditions of end friction against flat rods made of P18, 12X18H9T and other grades of steels during rotary-translational motion was also studied. The heating temperature of the samples and friction rods was measured using chromel-alumel thermocouples with a diameter of 0.2 mm on the device at a tape extension speed of 2,160 mm/min.

The processing of the results was carried out taking into account [5, 6] according to the expressions for elastic-plastic and plastic contacts:

Contour pressure

$$P_C = \frac{5,4}{E^4} \cdot \frac{HB^5(1-\mu^2)^4}{\Delta^2}, \quad (1)$$

$$P_c \geq 1.45\frac{1}{\Delta^2} \cdot \frac{HB^5(1-\mu^2)^4}{E^4}, \quad (2)$$

Approaching

$$\varepsilon = 0.125\left(8\frac{P_c}{HB} + 1\right). \quad (3)$$

Due to the significant influence of heating on the local change in the shape of the contacting surfaces of bodies and structural transformations, a thermocontact criterion for axisymmetric contact was used [6]:

$$\frac{\pi}{4A} \cdot \frac{f[(1+\nu_1)\cdot\alpha_1 + (1+\nu_2)\cdot\alpha_2]}{\lambda + \lambda_{21}} \cdot \left(\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2}\right) \cdot \omega R_{mr}^2 \cdot \sigma_h^2, \quad (4)$$

where f is the coefficient of friction; A is the mechanical equivalent of heat; ν_1, ν_2 are Poisson's coefficients; α_1, α_2 are thermal coefficients of linear expansion; λ_1, λ_2 are thermal conductivity coefficients; E_1, E_2 are elastic modulus of materials; σ_h is the maximum Hertz pressure; ω is the relative angular velocity; R_{mr} is the mismatch radius of curvature.

Both mass and linear wear was determined.

For wear-resistant steels with bainite, bainite-martensitic and metastable austenitic structure, the 30X2B8F deposited metal was taken as the main reference material.

The plasticity of the surface layer of the deposited metal and tool heat-treated steels was estimated by the values of the average elongation:

$$\delta_B = \frac{\delta_{max} + \delta_{min}}{2}, \quad (5)$$

where

$$\delta_{max} = \frac{0.08(h/d - 0.13)}{0.264 - h/d - 1.08(h/d^2)}, \quad (6)$$

$$\delta_{min} = \frac{0.75(h/d - 0.13)}{0.224 - h/d - 1.08(h/d^2)} \quad (7)$$

where "h" and "d" are, respectively, the depth of application of the indenter and the diameter of the hardness measuring imprint.

Heat resistance was determined by dependencies. The samples were heated to temperatures of 900, 925, 950, 970 and 1.000 K, exposure time — 4 hours with cooling and hardness measurement.

The number of cycles NK was taken as the characteristic of heat resistance before the destruction of the samples at the cross section.

3. Results and discussion

The low ability to strengthen tool steels and alloys leads to an increase in the rate of wear and premature transition to the stage of critical wear [7, 8]. Twinning and isolation of carbides in twins in metastable austenitic and secondary hardening steels increases the resistance to plastic shear at elevated temperatures, aggravating the destruction of working surfaces during friction [9–11]. The wear intensity of some of the studied steels is shown in Fig. 1.

After testing at the volumetric temperature of the working part of the sample T = 553...573°C, expansion of grain boundaries, shear lines, finer grain compared to lower layers were revealed in the contact volumes of the deposited metal of 30X2B8F and U120X4T3 types. The structure formed at the wear front is similar to the structure of the white zone in composition and is characterized by high microhardness. Also,

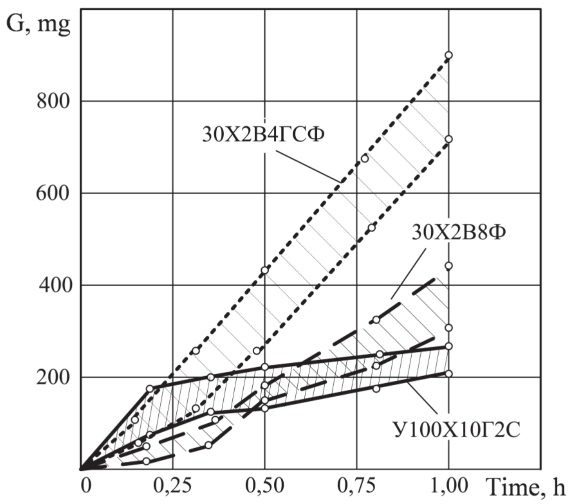

Fig. 1. Intensity of wear of the deposited metal. Mode parameters: TCM = 773 K, PA = 20 MPa, VBPP = 0.188 m/s, the material of the friction rod is P18 steel. The initial amount of austenite in the structure of the tested alloys: 30X2B8F — 5...7 %; 30X2B4GCF — 15 %; U100X10G2C — 95...97 %.

there is a specific change in the structure of the deposited metal in the contact zone and the underlying lower layers, as shown in Fig. 2.

Comparison of the dislocation density of the surface layer of the deposited metal with carbide and intermetallic reinforcement showed that directly at the wear surface, the dislocation density and the value of micro-distortions are slightly lower than at a distance of 20–40 μm (Fig. 2).

With an increase in the temperature of the friction rod to TCT — 823 K, the microhardness of the metal of the contact volumes decreased markedly (Fig. 3). The boundary layer is characterized by the structure of the "white zone" after high tempering.

In some samples of chromium-molybdenum deposited metal, a discontinuity outside the grains was revealed.

The structure of the tempered metal of the "white strip" of the 50X5M2B2H1F deposited metal changes in the wear surface by tempering products with austenite sections when the temperature of the friction rod increases from 823 K to 973 K.

Additional alloying of the deposited metal with nickel and manganese reduces AC1, and an increase in the concentrations of chromium, tungsten, molybdenum, on the contrary, increases the specified temperature, which is natural for thermal ef-

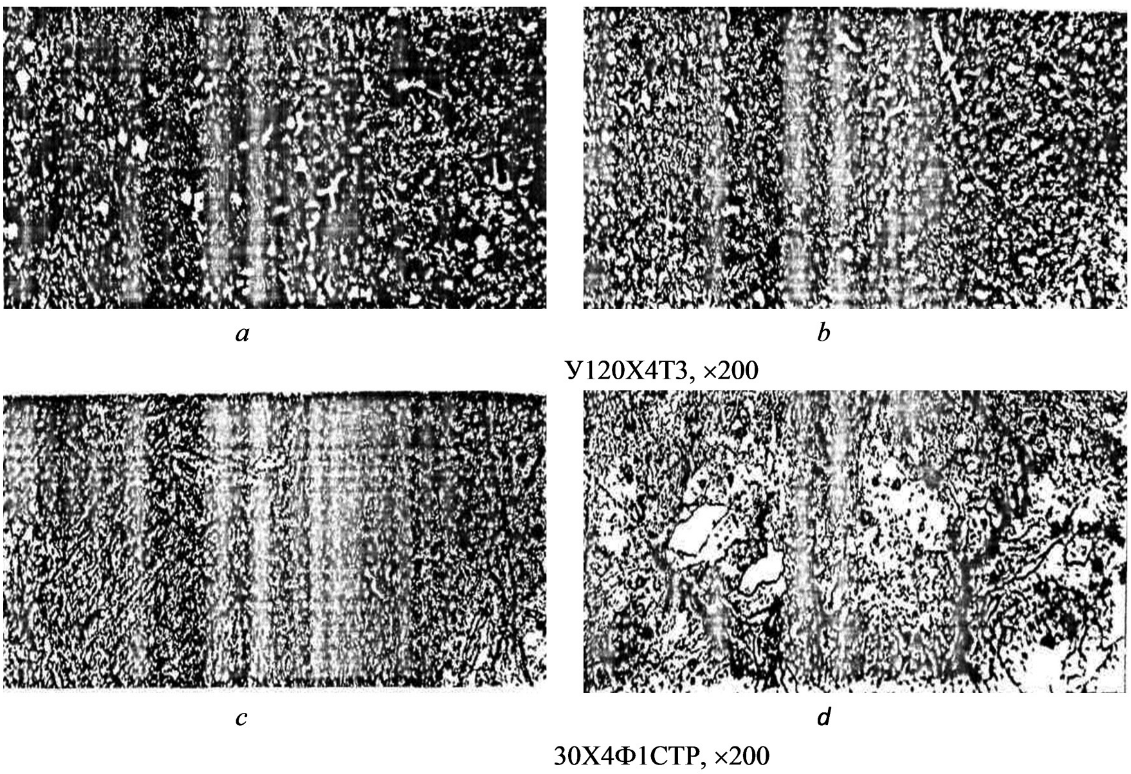

Fig. 2. Structure of the deposited metal after wear tests: a — at the surface; b — 2 mm from wear.

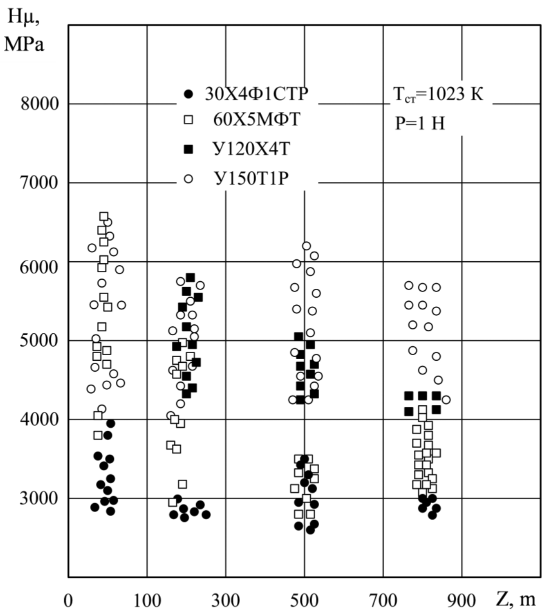

Fig. 3. Influence of the composition of the deposited metal on microhardness after wear tests.

fects with a low level of stresses acting on the metal.

With additional alloying of the chromium alloy with 3...4 % tungsten and molybdenum, the amount of austenite decreases as the concentration of these elements increases further. The nature of their influence on the temperature of A_{C1} is probably similar to chromium. A decrease in the conversion temperature $\alpha \to \gamma$ is facilitated by a change in the proportion of residual austenite associated with an increase in the content of carbon, manganese, nickel and a corresponding decrease in the effect of volumetric conversion. The formation of the "white stripe" section was observed at the volume temperature of the metal samples, which varies in a relatively wide range (Fig. 3). However, an increase in the temperature of the friction rod led to a significant decrease in microhardness and even to the absence (after testing) of the specified structure in the wear front.

Alloying of the chromium-tungsten deposited layer with 4–5 % nickel increased the proportion of residual austenite and decreased the AC1 temperature. However, the structure similar to the "white stripe" after wear is not registered, despite the fact that the maximum values of microhardness are approximately the same as that of the 30X2B8F alloy. The high microhardness of the metal of the contact layer and the absence of a "white stripe" structure are also characteristic of the deposited steels of the C–Cr–Mn–E systems (at Mn≤2...3 %, Cr≤6...7 %, Ti = 0.8...3.0 %), which were subjected to friction wear with rods under a temperature of ~ 823...1023°C.

Thus, the results of the experiments and the literature data confirm the possibility of the formation of a "white stripe" both in alloys having a high concentration of austenizing elements (Mn, C, Ni) and in materials alloyed with carbide-forming elements with a relatively low affinity with carbon (V, Mo). The occurrence of this structure during the wear of steels containing 8–10 % W was observed in a wide range of actual pressures and volumetric temperatures. Reducing the concentration of tungsten makes it easier to prevent the formation of a "white stripe".

The influence of the "white stripe" on wear resistance can be attributed to structural changes during the process of its formation, temperature and time intervals, as well as stresses applied to it.

The formation of a "white stripe" as a result of dispersion and deformation hardening of martensite or the formation of a bainite-martensitic matrix at temperatures below the temperature of reverse martensitic transformation AH causes a low level of plasticity margin of the metal of the contact layer.

4. Conclusion

The conducted studies confirm the possibility of the formation of a "white stripe" both in alloys having a high concentration of austenizing elements (Mn, C, Ni) and in materials alloyed with carbide-forming elements with a relatively low affinity to carbon (V, Mo).

References

1. N.E.Kalinina, D.B.Glushkova, A.I.Voronkov, V.T.Kalinin, *Functional Materials*, **26**, 514 (2019).
2. D.B.Hlushkova, V.A.Bagrov, S.V.Demchenko et al., *Problems of Atomic Science and Technology*, **140**, 125 (2022). https://doi.org/10.46813/2022-140-125
3. V.S.Vahrusheva, D.B.Hlushkova, V.M.Volchuk et al., *Problems of Atomic Science and Technology*, **140**, 137 (2022). https://doi.org/10.46813/2022-140-137
4. B.Trembach, O.Balenko, V.Davydov et al., IEEE 4th International Conference on Modern Electrical and Energy System (MEES), 01-06 (2022). doi:10.1109/MEES58014.2022.10005657

5. D.N.Garkunov, Tribotechnics, Design, Manufacture and Operation of Machines, MSHA, Moscow (2002).
6. Yu.N.Drozdov, V.G.Pavlov, V.N.Puchkov, Friction and Wear in Extreme Conditions, Mashinostroenie, Moscow (1986).
7. B.Trembach, V.Vynar, I.Trembach et al., *Problems of Tribology*, **27**, 34 (2022). https://doi.org/10.31891/2079-1372-2022-105-3-34-40
8. B.O.Trembach, M.G.Sukov, V.A.Vynar et al., *Metallofiz. Noveishie Tekhnol.*, **44**, 493 (2022). https://doi.org/10.15407/mfint.44.04.0493
9. V.A.Bagrov, V.N.Kolyanov, *Automatic Welding*, **11**, 44 (2000).
10. V.N.Kalyanov, A.V.Novitskaya, *Welding Production*, **10**, 24 (1997).
11. V.N.Kalyanov, V.A.Bagrov, *Welding Production*, **2**, 35 (2003).