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OPTIMIZATION OF WEAR OF SHAFT-SLIDING MATING SURFACES OF SHIPBORNE TECHNICAL DEVICES (STS)

Parts statement of the problem in general form and its relation to important scientific or practical tasks

In researches of O.A.Bannikh, V.V.Berezovskaya, H.Burns, V.M.Blinov, R.Boucher, V.G.Gavrilyuk, Yu.N.Goichenberg, L.Zhekova, L.M.Kaputkina, L.G.Korshunova, M.V.Kostina, V.G.Prokoshkina, D.Rauers, C.Rashev, J.Tervo, M.A. Filippov and others have shown the prospects of achieving high strength, ductility, corrosion resistance and wear resistance of stainless steels through the introduction of significant concentrations of nitrogen. In connection with the development of new classes of economically alloyed high-nitrogen steels, an in-depth analysis of the tribological properties of nitrogen-bearing steels (including cast steels) under various conditions of contact loading seems relevant.

Deformation of material microvolumes under conditions of simultaneous influence of external compressive and shear stresses, active development of the rotational mechanism of plasticity lead to appearance of nanocrystalline friction structures (NFCS) in a thin (up to 10 microns) surface layer. It is of interest to consider possibilities of formation of NCST on a surface of iron alloys (including high-strength and low-plastic) not only at adhesive, but also at abrasive wear.

NCST formed in various metals and alloys are often characterized by relatively close average values of fragment sizes and the degree of their misorientation. However, these morphologically similar structures, as a rule, have different tribological and strength properties. In this regard, the question of interrelation between the parameters of the initial structure of iron alloys (type of crystal lattice, alloying level of the solid solution, the presence of strengthening phases, etc.) and the properties of NCST is important. The solution of the problem of further significant increase in the tribological and service properties of iron alloys can be associated with the creation in their surface layer of NCST of optimized chemical and phase composition, defectiveness level, possessing high strength, toughness, ability to intensive plastic deformation, as well as large adsorption, diffusion and chemical activity.

The possibility of nanostructuring in the cold state not only of relatively plastic, but also of high-strength, hard-deformable alloys (for example, hardened steels) distinguishes frictional processing from such methods of production of bulk nanocrystalline materials as equal-channel angular pressing, torsion under pressure, multi-axial deformation.

Frictional treatment, which is one of few real methods of formation of nanocrystalline state in materials with martensitic structure, which is the basis of high-strength tool, die and structural steels, gives an opportunity to conduct a systematic study of strength and tribological properties of nanocrystalline martensite of different composition. Such alternative methods of nanostructuring of high-strength materials as various ball treatments (shot blasting, SMAT, etc.) and ultrasonic treatment with a pulsating tool form a different stress-strain state in the surface layer under the action of impact influences than in case of frictional treatment carried out in sliding friction conditions. Since frictional impact can destroy (wear) the material, it is important to identify the optimal machining conditions that ensure the accumulation of maximum strain in as thick a surface layer of alloys as possible.

Wear resistance is a multifactorial parameter and its prediction on the basis of standard measured properties (hardness, mechanical properties) is often erroneous, since these characteristics are often not reliable criteria of wear resistance of STS parts surfaces. Assessment of wear resistance of ship parts and units in production conditions is extremely difficult. Therefore, in order to ensure high serviceability of wearing ship parts and tools, along with the development of materials and methods of their effective hardening, it is important to create non-destructive ways of wear resistance prediction.

The purpose of this study is:

to study changes in the structure and hardening of carbonaceous α-martensite under different frictional loading conditions, including at reduced (down to -196°C) temperatures;

in study of influence of carbon content in martensite, presence of residual austenite and carbide phases on wear resistance and strain hardening under different types of wear of carbonaceous, low-alloy and cemented steels.

Key words: ship equipment, martensite transformation, nanostructuring, nanocrystalline martensite, frictional effects, "shaft-sliding bearing" mating.

Summary of the main material of the study

Qualitatively identical character of changes of a profile of X-ray lines of tetragonal martensite in the conditions of friction in the environment of nitrogen at room and negative temperatures (fig. 1), and also the similar level of hardness of surfaces of friction formed at temperatures from +20°C to -196°C (fig. 2) show that the processes of deformation dynamic aging in tetragonal martensite, which are purely deformational in nature, actively develop even at low (to -196°C) temperatures, when the diffusion mobility of carbon atoms in martensite is extremely low. In this case, the dislocations are mobile and capture carbon atoms during their movement.

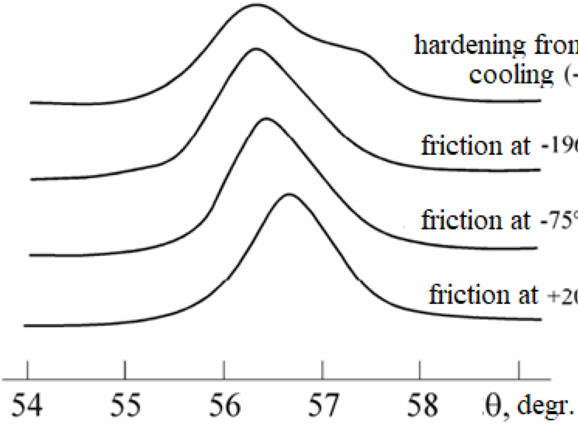

Fig.1.Retgene diffractograms of martensite lines of U8 steel in the undeformed state and after frictional loading with a carbide indenter.

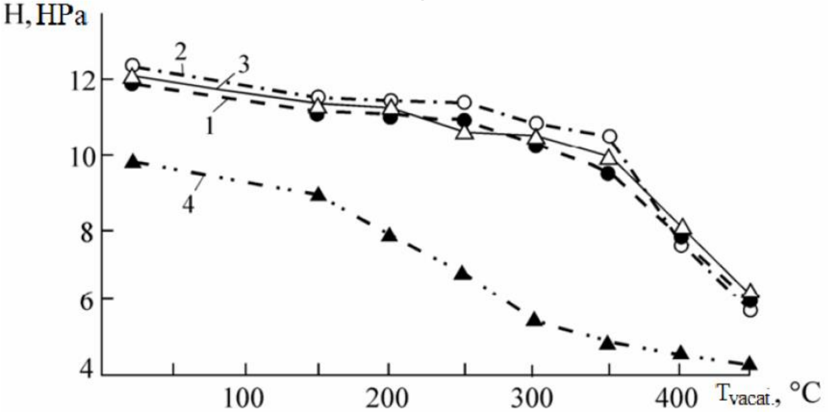

Fig.2.Effect of tempering temperature (2 h) on the microhardness of friction-hardened U8 steel: 1, 2, 3 correspond to loading temperatures -196, -75, +20°C; 4 - initial quenched state.

Change of frictional loading temperature in the range from +20 to -196°C has no noticeable influence on the character of dependence of high-carbon steel surface hardness on tempering temperature (see fig. 2). The main reason for the observed increased heat resistance of friction deformed martensite of steel U8 is the high bonding energy of dislocations with carbon atoms, which ensures preservation of strong fixing of dislocations in martensite during tempering, as well as frictional heating, as evidenced by the experimental data on the increased wear resistance of hardened steel U8 under high-speed friction without and with lubrication.

Residual austenite in hardened high-carbon steels is not only inferior in abrasion resistance to unlubricated cooling martensite but also provides the maximum level of wear resistance in conditions of micro cutting (corundum wear) after high-temperature (> 1000°C) hardening. This is due to the partial transformation of austenite under loading into highly dispersed (nanocrystalline) deformation martensite, as well as the positive effect of austenite on fracture toughness. The resulting strain martensite contains the same amount of carbon as high-carbon austenite, and is thus an unconducted martensite with high hardness and the ability to intensively harden during wear. A sharp drop in the intensity of γ->α transformation along the depth of the surface layer was recorded in 1100°C-hardened U15 steel (with an initial austenite content of 65-70 vol.%) subjected to abrasive impact, while a significant proportion of austenite in layers 5 μm thick (45 vol.% γ), 1 μm thick (20 vol.% γ) and in the wear products (20 vol.% γ) was retained. In contrast to the corundum test, the increase in the amount of metastable residual austenite to 60-70 vol.% when the quenching temperature is increased to 1000-1200°C leads to reduction of wear resistance due to the reduction of the positive role of the "framework" of cooling martensite plates in limiting the processes of polydeformation (fatigue) fracture of the steel surface.

Low tempering in the temperature range of 100-250°C causes sharp decrease in resistance of steels with high-carbon martensite structure to abrasive (fig. 3) and fatigue wear, despite the relatively slight decrease in hardness of hardened steels at low-temperature tempering due to their hardening by ε-carbide phase.

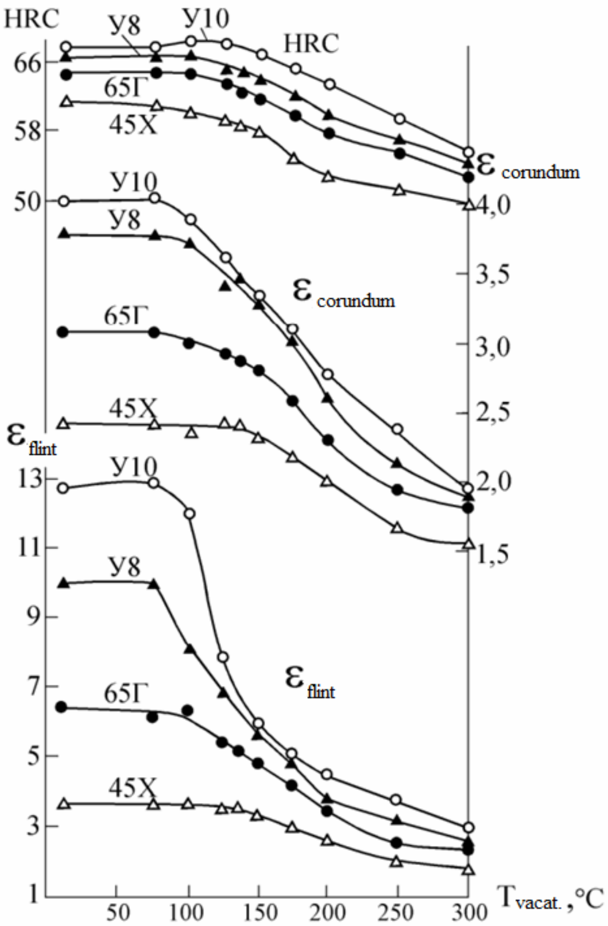

Fig. 3. Effect of tempering temperature on HRCe hardness and abrasion resistance ε of laser quenched steels (45Kh, 65G, U8) and in water from 1000°C (U10) with subsequent cooling at -196°C (U8, U10).

The fall of wear resistance is caused by the reduction of carbon concentration in α-solid solution at low tempering and, as a consequence, the reduction of the effect of the positive influence of strain dynamic aging of martensite on the strain hardening and wear resistance of steel surfaces. Thus, the hardening ability during abrasive wear of low-temperature (at 200°C) martensite is 2-2.5 times lower than that of tetragonal high-carbon martensite.

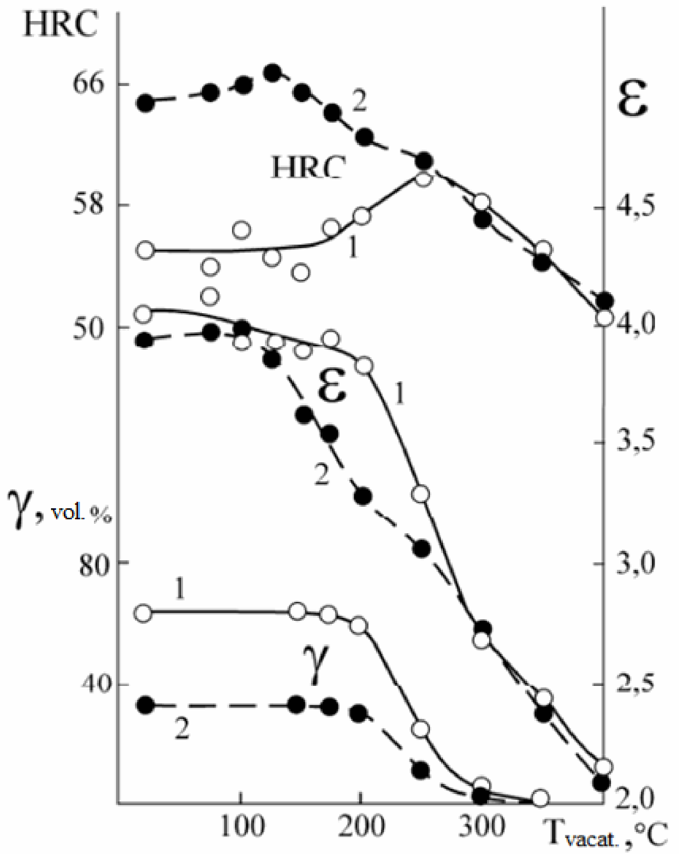

Fig. 4. Influence of tempering temperature on hardness HRCe, amount of residual austenite y in structure and abrasive wear resistance ε of steel U15:
1 - hardening from 1100°C;
2 - quenching, temp. -196°C

Optimization of low-temperature tempering aimed at keeping as much carbon in martensite as possible is an important reserve for increasing wear resistance of steels. The alloying elements (Mo, V, Mn, Si, Cr, Ni in quantities up to 4 %), as well as excess cementite do not eliminate the drop in wear resistance of tool and cemented steels at low tempering. However, alloying makes it possible to significantly increase the wear resistance of iron-carbon alloys at medium (300-450°C, Si) and high (600°C, V and Mo) tempering temperatures. Figure 4 shows that the metastable residual austenite in an amount up to 70 vol.% effectively slows down the decline in abrasion wear resistance of hardened iron alloys in the low tempering temperature range, at which the austenite retains its thermal stability and, accordingly, increased wear resistance, which is not inferior to the wear resistance of un tempered tetragonal martensite. The level of abrasive wear resistance of high-carbon steels increases with the increase in the volume fraction of tempering carbides, but depends little on the degree of coagulation of cementite, the presence of graphite inclusions in steel and on grain size.

The main reasons for the increased wear resistance of iron alloys hardened by laser or electron-beam exposure are:

1) effective suppression of martensite self-tempering, which provides it not only great initial hardness, but also the best conditions for the development of deformation dynamic aging;

2) the possibility of formation of a significant amount of metastable residual austenite due to high-temperature (up to melting) heating of the surface. After tempering, no significant no significant differences in the behavior of laser and volume hardening structures of 45Kh, 65G, U8, ShKh15 and 20KhNZA (cemented) steels.

High wear resistance in sliding friction conditions of ferrite-martensitic structures of incomplete laser hardening of low-carbon steels has been established due to formation on the surface of a high-strength supporting "framework" of martensitic areas arising on the place of former pearlitic colonies. At friction with lubrication the formation of the increased tribological properties of two-phase laser hardening structures is also promoted by the appearance of oil-retaining micro-cavities in the place of worked-out ferrite areas.

The notions of increased wear resistance of carbon-saturated metastable martensitic and austenitic structures were used in the development of two new methods of heat treatment of STS parts made of cemented steel. Resistance of the bearing unit to their abrasion and contact-fatigue wear is increased due to laser hardening of ball and roller racetracks of the bearing unit and optimization of low tempering mode (after volume hardening), which form in cemented steel the structure of high-tetragonal martensite with some amount of metastable austenite. Both methods provide for the possibility of cold treatment to reduce the share of austenite and increase the load-carrying capacity of the cemented surface.

In order to develop the technology of laser hardening of STS crankshafts a set of studies aimed at increasing the wear resistance and resistance to fatigue failure of high-strength cast iron VCh60-2 using the treatment with continuous radiation of CO2 laser and subsequent thermomechanical operations (tempering and surface plastic deformation by running-in) was carried out.

The possibility of using highly sensitive eddy-current and coercitimetric methods to assess the wear resistance of structural, tool, bearing, cemented steels and high-strength cast iron subjected to laser or volume hardening, cold-treatment and tempering has been established. High efficiency of eddy-current method application for detection and certification of wear resistance layer formed on the surfaces of steels and cast irons during hardening is shown.

Conclusions

1. The positive effect on the wear resistance of deformation dynamic aging of tetragonal martensite and deformation transformation of metastable residual austenite can be effectively used to increase the resistance to adhesion and abrasion wear of high-alloys containing a significant amount of high-strength special carbides in the structure.
2. The influence of carbon content in martensite, presence of residual austenite and carbide phases on wear resistance and strain hardening under different types of wear of carbon, low-alloy and cemented steels is shown.

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