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The influence of hydrogen saturation on the wear mechanism of steel

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Abstract

The tribological characteristics of hydrogenated steel 60C2 with different structural states were compared with the obtained results of studies of friction surfaces by physicochemical methods, which allowed us to draw a conclusion about the relationship between friction and wear indicators with the processes occurring on the surface of the material during friction, and the significant influence of hydrogen present in the contact zone on them. It was proven that during friction on the contact surface of hydrogenated steel 60C2, regardless of its structural state, the process of formation of secondary structures occurs, which determine the process of friction and wear of the material. Reduction of the wear intensity of steel 60C2 with a tempered martensite structure (300°C) is accompanied by the formation of secondary structures on the surface, which have a higher resistance and shield the base material from direct contact and destruction. In addition, the saturation of the material with hydrogen changes the nature and mechanism of formation of secondary structures, which in turn leads to a change in the mechanism of friction and wear of the material.

Keywords: friction, wear, hydrogen, surface structures.

Introduction

Under friction, in almost any conditions, thanks totribochemical processes in the contact zone, hydrogen is released due to the decomposition of hydrocarbons in lubricants, fuel, plastics, wood and other environments, as well as the diffusion of hydrogen present in the steel under the influence of various processes in the surface layer zone [1]. In this case, under the influence of hydrogen, not only mechanical but also tribological characteristics of materials change significantly [1-4]. There is some information in the literature on the effect of hydrogen on the properties of materials, but they are advisory in nature and do not allow for a full characterization of its effect on a specific material. In view of the fact that parts made of 60C2 steel are used in friction pairs under conditions that do not exclude hydrogenation of the material, it became necessary to conduct studies on friction and wear taking into account the effect of hydrogenation, to analyze the change in the physicochemical situation in the contact zone under the influence of hydrogen.

The purpose of the work is was the study of the mechanisms of wear of materials, using the example of steel 65G, when they are hydrogenated. As well as the processes occurring on surfaces during their friction under hydrogenation conditions.

Materials and research methods

For the research, steel 60C2 was selected, used in industry (sealing and spring rings, in the manufacture of wire tools, springs for automobiles and rolling stock, etc.).

Various structural states of steel were achieved by quenching from 870°C and their subsequent tempering at different temperatures (200, 300, 400 and 500°C) for two hours.

Tribological studies of metals under dry sliding friction conditions were carried out on a universal friction machine model 2168. Tests were carried out using the disk-finger friction scheme on standard samples.

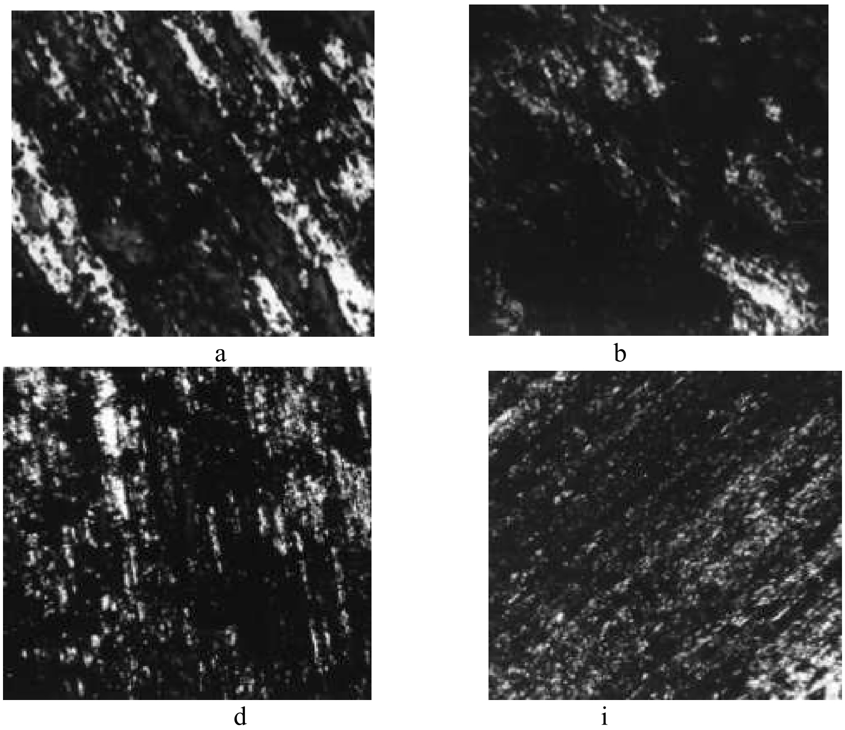


Fig. 1. Friction surfaces of 60C2 steel with different structural states, studied in air at constant pressure (10 MPa): a - tempering structure 200°C (0.2 m/s);b - 300°C (0.2 m/s); d - 400°C (0.2 m/s); i - 500°C (0.4 m/s) (×152)

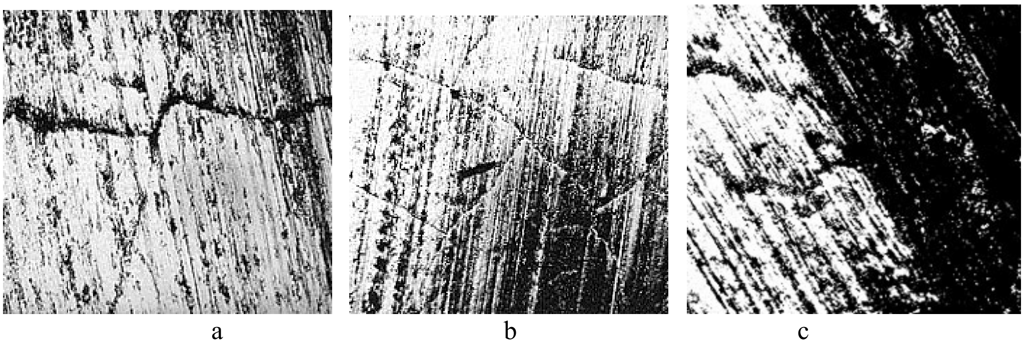
To study the effect of hydrogen on the characteristics of 60C2 steel with different structural states, samples were saturated with hydrogen using the cathodic polarization method in a 10% H_2SO_4 solution for 1 hour.

With the development of regularities, a complex of modern physico-chemical methods of structural-phase analysis, which is important for the examination of surface balls, is lost and worn out. In this case, the comprehensive research methodology included metalography; scanning electron microscopy (scanning electron microscope JSM-840); X-ray structural phase analyzer (DRON-UM1 diffractometer).

Research results and their discussion

The laws of transformation of mechanical energy into internal energy during friction are determined by loading conditions, the structure of materials and the action of the environment. At this stage of the work, the goal was achieved - determining the effect of hydrogen on the structure, phase composition of the surface layer of contact pairs, the degree of plastic deformation. This will allow a qualitative assessment of the results of tribological tests.

The performed macroscopic studies of the surface allow us to draw a conclusion about the qualitative and quantitative difference of the films formed on the friction surfaces of 60C2 steel tested in air (fig. 1) and after hydrogenation (fig. 2), depending on the test conditions. The friction surfaces of the samples tested after hydrogenation are covered with a network of microcracks (fig. 2 a, c, d), whereas they are absent when tested in air (fig. 1). Micro cracks formed on the surface films and in the near-surface layer of the material, which indicates embrittlement of the material surface under the influence of hydrogen.



d i g

Fig. 2. Friction surfaces of 60C2 steel with different structural states, P=10 MPa, saturated with hydrogen at different current densities: a - tempering structure 300°C (0.4 m/s, 1 A/dm^2); b - 400°C (0.2 m/s, 1 A/dm^2); in - 500°C (0.4 m/s, 1 A/dm^2); g - 300°C (0.2 m/s, 4 A/dm^2); d - 400°C (0.2 m/s, 4 A/dm^2); f - 500°C (0.4 m/s, 4 A/dm^2) (×152)

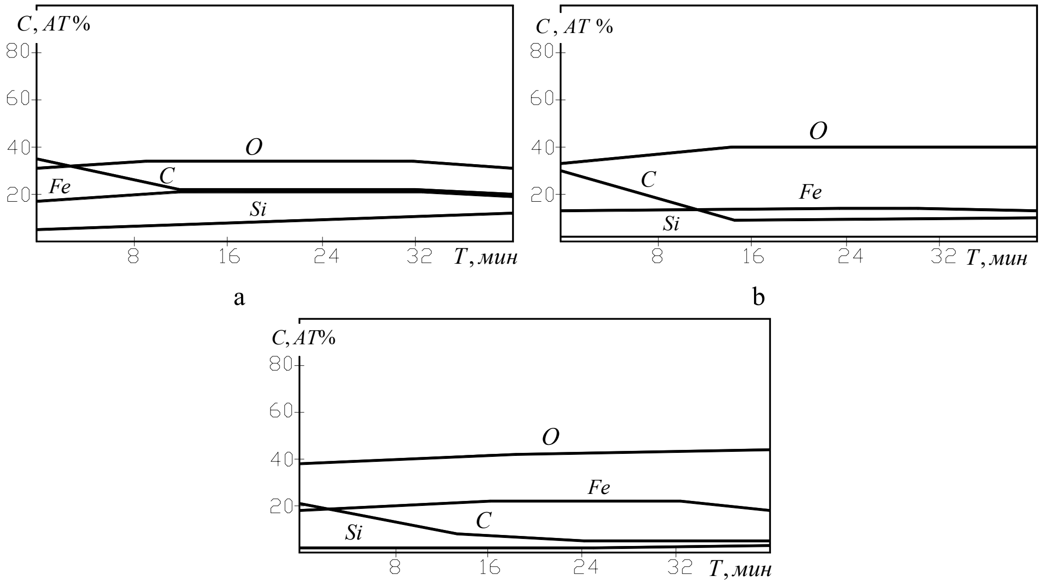
Comparing the results obtained in the study of the wear intensity of 60C2 steel in different structural states with the corresponding friction surfaces, a certain pattern can be seen between them - an increase in the number of cracks on the friction surfaces is accompanied by an increase in the wear intensity of the material and vice versa - a decrease in the number of cracks on the friction surfaces is associated with a decrease in the wear intensity of the material.

During friction, the surface is deformed due to tangential stresses, the relaxation of which, when tested in air, occurs due to an increase in plastic deformation of the contact points. In our opinion, hydrogen present in the contact zone activates the processes of self-organization of the surface and promotes the formation of fairly brittle films, which, under the action of the touch. The stresses are destroyed, forming a network of microcracks, and intensifies the wear process.

On friction surfaces of steel 60C2 with a higher tempering structure (400°C and above) (fig. 2 c-e), saturated with hydrogen, a less intense formation of cracks was noted, which can be explained by an increase in the plasticity of the material and completely different conditions for the formation of microfilms, and with an increase in the friction speed and pressing force (fig. 2 g, e), surface cracks were not detected.

To explain the processes occurring during friction and wear of hydrogenated steel 60C2 with different structural states, a study of the chemical composition of friction surfaces and secondary structures was conducted.

In fig.3 shows the nature of the distribution of elements on the friction surface of hydrogenated steel 60C2, with a tempering structure of 300°C, for different speeds of sliding friction. From which it follows that the chemical composition of the friction surface depends on the structural state and changes under the influence of hydrogen.



c

Fig. 3. Distribution of chemical elements of hydrogenated steel 60C2 by the depth of the friction surface, depending on the etching time, at P = 10 MPa: a - V = 0.2 m/s; b - V = 0.3 m/s; c - V = 0.4 m/s

When studying the profiles (fig. 3) of the distribution of elements on the friction surface of hydrogenated steel 60C2, it should be noted that the oxygen content on the surface and in the near-surface region increases, as well as the carbon content decreases. In addition, iron was found on the friction surface, the amount of which changes with depth (fig. 3 a, b, c). The presence of these elements indicates the predominant possible formation of iron carbides and oxides, whereas Fe is absent when tested in air.

It was found that the increase in the friction speed of hydrogenated samples leads to depletion of the surface in carbon and its amount is significantly less than in air. The oxygen content on the surface is almost the same, does not depend on the research modes, and its concentration increases monotonously with depth. The amount of oxygen on the friction surface of hydrogenated steel 60C2 is significantly greater than in air, which can be explained by the presence of hydrogen in the contact zone.

In all cases, silicon was found on the friction surface of hydrogenated 60C2 steel, the amount of which increases with depth for low friction speeds (up to 0.2 m/s) (fig. 3 a), with increasing speed - its amount on the surface and in the near-surface zone is the same (fig. 3 b, c).

The presence of silicon in the contact zone makes it possible to form chemical compounds of silicon with elements of the environment, especially oxygen. At the same time, no depletion of the inner layers of silicon is observed due to saturation of the surface of hydrogenated samples with it, in contrast to the results obtained in air. The amount of silicon registered on the hydrogenated friction surface is less than in air. That is, it can be stated that during friction of hydrogenated samples, silicon diffusion into the contact zone from the inner layers does not occur.

When considering the formAuger spectrum of carbon obtained from friction surfaces of hydrogenated steel 60C2, it can be noted that it corresponds to the carbide phase. In our opinion, this is due to the fact that iron and manganese form compounds with carbon, while other elements that can lead to carbide formation have not been registered.

The presented results of the study allow us to conclude that as a result of friction of hydrogenated steel 60C2, a change in the chemical composition of the surface and the near-surface region occurs in comparison with the volume of the sample, which is associated with the activation of the surface layer and the formation of secondary structures on them, which, as is known, affect the process of friction and wear. In addition, the qualitative and quantitative nature of the secondary structures formed in the presence of hydrogen differs from those formed in air, which confirms the influence of hydrogen.

The use of the SIMS method made it possible to analyze changes in the microstructure in thin surface friction layers of hydrogenated steel 60C2 with different structural states, and to establish the nature of the phases, their crystalline structure, and the parameters of the unit cell necessary for identifying the phases and composition within the region of their homogeneity.

The study of friction surfaces of hydrogenated 60C2 steel in the transmission microdiffraction mode allowed us to record diffuse halos (fig. 4a), the number of which reflects the qualitative picture of the surface layer activated by friction after elastic-plastic deformation [6, 7, 10]. The electron diffraction pattern indicates that the microstructure of the friction surface in the presence of hydrogen of 60C2 steel samples has a finely dispersed structure and consists of a mixture of phases of material components, contacting pairs and products of interaction with atmospheric oxygen.

It should be noted that the order of dispersion of the friction surfaces studied in air and after hydrogenation is practically the same; however, a slight increase in the dispersion of the friction surface studied in the presence of hydrogen is noticeable, which is apparently due to the fact that hydrogen promotes greater oxidation of the structure.

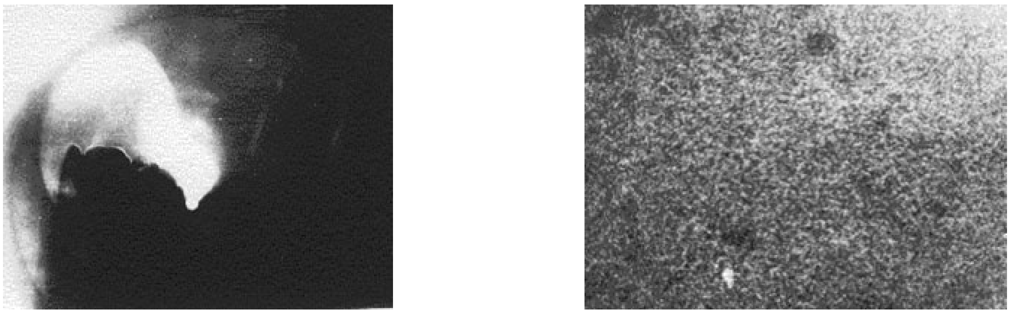

a b

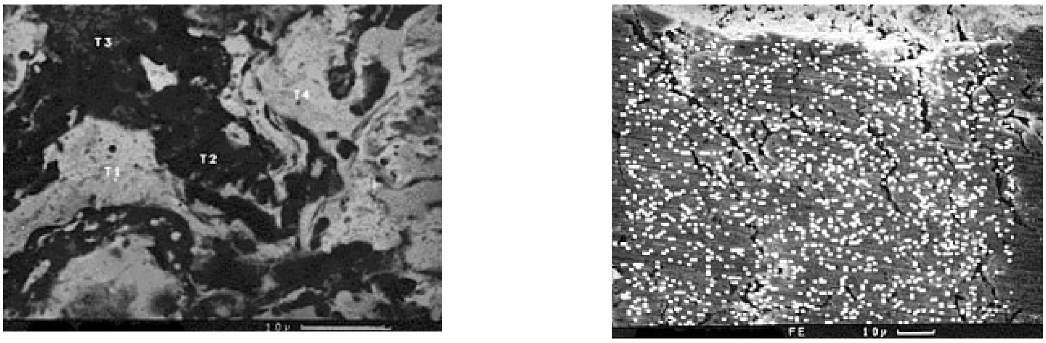
Fig. 4. Electron diffraction pattern of surface friction layers (a) and distribution of elements on the friction surface (b) of hydrogenated steel 60C2 with a tempering structure of 300°C

According to the stoichiometric composition, the microstructure of the friction surface after hydrogenation, as in air, is a complex, difficult to activate complex in the form of a finely dispersed mixture of oxides of Fe, Mn, Si and complex spinel phases of the $FeMn_2O_4$ type, which are formed on the surfaces of the material during the friction process.

On the friction surfaces of hydrogenated steel 60C2, with different tempering structure, the appearance of new structural components was noted, representing a practically uniform distribution of ellipsoid fragments over the friction surface (fig. 4 b), distinguished by additional dissolution of carbide phases in the matrix. On the friction surfaces of hydrogenated steel 60C2, the presence of uniformly distributed ultra-dispersed new formations similar to those found on the friction surfaces in air was not detected.

X-ray phase analysis hydrogenated friction surfaces, carried out on a DRON-UM1 diffractometer, showed that the structure of the samples is a solid solution based on iron and a finely dispersed mixture of strengthening phases, mainly in the form of Fe, Si carbides and intermetallic compounds. The presence of a solid solution of Fe_2O_3 in the surface layers was noted. When determining the physical broadening of the lines, caused by the dispersion of crystals and distortion of the crystal lattice, on friction surfaces in the presence of hydrogen of samples with a tempered martensite structure (300°C), the absence of FeO was established, apparently due to its thermodynamic instability and oxidation to Fe_3O_4. Thus, a decrease in the oxidation rate and the intensity of wear product formation leads to an increase in the wear resistance of the material with such a structural state.

Results of physical-chemical and the results of the microphase analysis of friction surfaces of hydrogenated 60C2 steel using an electron microscope are shown in fig. 5. It follows from them that the friction surfaces differ qualitatively and quantitatively (fig. 5a) from the surfaces obtained during similar tests in air. Several types of secondary structures can be distinguished on the surfaces obtained in the presence of hydrogen, differing in chemical composition and in different ability to reflect light (T1, T2, T3, T4). Let us recall that other types of secondary structures were obtained in air: T5, T6, T7, T8. Supersaturated solid solutions of iron with dissolved oxides of Si, Mn have a light shade, which can be attributed, in our opinion, to secondary structures of the second kind, according to the classification proposed by V.I. Kostetsky [6-9]. The following should be noted: the amount of dissolved oxides of Si, Mn on the friction surfaces in the presence of hydrogen is less than in air. And, as is known, silicon dioxide found on the friction surface promotes the formation of glass-forming oxide, which has unique physical and chemical properties - sufficiently high hardness without brittleness, and on friction surfaces examined in air, the amount of silicon oxide is significantly greater than after hydrogenation. Obviously, hydrogen affects the process of SiO formation, namely, the presence of hydrogen reduces the amount of silicon oxide formed. This, in turn, can also explain the increase in intensity wear resistance of hydrogenated steel 60C2 with a low-temperature tempering structure (up to 400°C).



a b

Fig. 5. Formation of secondary structures on friction surfaces (a) and distribution of iron on friction surfaces of hydrogenated steel 60C2 with a tempering structure of 300°C

Fig. 5 b shows the distribution of iron on the friction surface of hydrogenated steel 60C2, from which it is evident that the amount of iron on the friction surface obtained during the study in air is significantly less than in the presence of hydrogen (fig. 5 b). This confirms the result we obtained earlier. In addition, the iron is distributed uniformly over the surface of the material. A large number of micro cracks are observed on the hydrogenated friction surface, which can obviously explain the increase in the wear rate of the material saturated with hydrogen.

Conclusions

The conducted qualitative and quantitative analysis of friction surfaces of samples made of hydrogenated steel 60C2, with different structural states, allows us to draw the following conclusion:

- the chemical composition of the friction surface of hydrogenated steel 60C2 differs from the chemical composition of the volume, the friction surface and the near-surface region contain iron and are enriched with carbon, the concentration of which decreases with increasing friction-sliding speed. This promotes the formation of secondary structures consisting mainly of iron oxides and reduces the amount of silicon oxide formed, which in turn reduces the wear resistance of the material in the presence of hydrogen;
- the iron content on the surface increases with increasing load (speed); with increasing speed, a new phase, iron carbide, is formed in the near-surface region;
- hydrogen significantly affects the composition of the friction surface and the near-surface region, which is manifested in its greater oxidation through the predominant formation of iron oxide and lesser silicon oxide, the formation of more brittle secondary structures that do not contribute to the wear resistance of friction pairs.

Comparing the tribological characteristics of hydrogenated steel 60C2, with different structural states, with the obtained results of studies of friction surfaces by physicochemical methods, it is possible to draw a conclusion about the relationship between the friction and wear indicators with the processes occurring on the surface of the material during friction, and the significant influence of hydrogen present in the contact zone on them. It has been proven that during friction on the contact surface of hydrogenated steel 60C2, regardless of its structural state, the process of formation of secondary structures occurs, which determine the process of friction and wear of the material. Reduction of the wear intensity of steel 60C2 with a tempered martensite structure (300°C) is accompanied by the formation of secondary structures on the surface, which have a higher resistance and shield the base material from direct contact and destruction. In addition, the saturation of the material with hydrogen changes the nature and mechanism of formation of secondary structures, which in turn leads to a change in the mechanism of friction and wear of the material.

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В.В. Щепетов, С.С. Бись, М.Р. Бялик, В.Ю. Медведчук, Я.С. Бись. Вплив наводнювання на механізм зношування сталі.

У статті проаналізовано трибологічні характеристики наводненої сталі 60С2, з різним структурним станом, з отриманими результатами досліджень поверхонь тертя фізико-хімічними методами. Це дозволило зробити висновок про взаємозв'язок показників тертя і зношування з процесами, що протікають на поверхні матеріалу при терті, і значного впливу на них водню в зоні контакту. Доведено, що в процесі тертя на поверхні контакту наводненої сталі 60С2, незалежно від її структурного стану, відбувається процес утворення вторинних структур, які визначають процес тертя та зношування матеріалу. Зниження інтенсивності зношування сталі 60С2 зі структурою мартенситу відпуску (300°С) супроводжується утворенням на поверхні вторинних структур, що мають більш високу стійкість і екранують основний матеріал від безпосереднього контакту та руйнування. Крім того, насичення матеріалу воднем змінює характер та механізм утворення вторинних структур, що у свою чергу призводить до зміни механізму тертя та зношування матеріалу.

Ключові слова: тертя, знос, водень, поверхневі структури