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EFFECT OF SURFACE MODIFICATION OF 5KHV2S STEEL ON THE MECHANISM AND INTENSITY OF CONTACT WEAR

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The paper presents the experimental study of the contact wear of 5KHV2S steel after surface modification. It is shown that without hardening of the surface layer, 5KHV2S steel is capable of satisfactory operation when a pulsating contact stress of 970 MPa is applied. The most qualitative type of surface modification is the hardening of the surface layer by nitrocementation carried out before quenching and tempering. The proposed technology of volumetric-surface hardening, including forging in a new forging tool, chemical-thermal treatment, quenching and low-temperature tempering, provided the possibility of increasing the pulsating contact stress to 1 100 MPa, and the operation period during the first 13 000 loading cycles gives wear of the working surface no more than 0,1 mm.

Keywords: steel 5KHV2S, wear, surface layers, pulsing contact loads, nitrocementation

INTRODUCTION

The use of 5KHV2C steel as a material for stamping tools is an attractive trend due to the absence of ledeburite phases in the steel. The complex of alloying elements in combination with a sufficient amount of carbon provides high strength, hardness and viscosity [1]. At the same time, in many cases, the failure of the cold stamping tool occurs due to unsatisfactory indicators of contact endurance. The mechanism of this kind of destruction is largely related to the ability of the material to extinguish the energy of external impact due to intracrystalline plasticity. At the same time, macroplasticity, which causes large-scale changes in the stamp engraving, is unacceptable. Therefore, the initial requirements for high metal hardness, at a level of at least 56 - 57 HRC, must be combined with a certain structural ratio. It is the interaction of the phase and structural components of the composite material that can provide both accelerated nucleation of contact fatigue cracks and their propagation exclusively on the microscopic scale of the outer layer of the working surface. The second scenario is more preferable. This is due to the fact that conditions are created for controlled and controlled wear of the engraving. At the same time, the operation of the die before the stage of forging exit from the tolerance will meet the conditions of the planned operation of the stamping equipment without sudden emergency stops. The mentioned concept is usually achieved by adaptive hardening of the surface of a particular material in various ways. The productivity of hardening is checked using the original test procedure.

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MATERIALS AND METHODS

5KHV2S steel was the research object. Samples were tested for resistance to contact wear after hardening by volumetric heat treatment, as well as with additional modification of the surface layer by diffusion hardening. Nitrocementation was applied at a temperature of 880 °C. The medium for performing chemical-thermal treatment (CTT) was charcoal modified with urea. The duration of the CTT was 6 and 8 hours. Additional parameters of the technological process of volume-surface hardening of the 5KHV2S steel were the modes of initial thermomechanical processing of workpieces. Two batches of blanks were tested – one of them in the delivery state after rolling on a standard rod, the second was additionally forged in a forging tool that allows for intensive plastic deformation in the entire volume of the deformable metal [2]. The finishing treatment of all batches of samples, regardless of the type of previous influences, was completed by quenching at a temperature of CTT - 880 °C and low-temperature tempering for 2 hours at a temperature of 200 °C.

To carry out contact wear tests, initial samples of a special shape were prepared (Figure 1) from blanks subjected to forging in a new forging tool + various modes of thermal and thermochemical processing, as well as from blanks subjected only to various modes of thermal and thermochemical processing.

The accumulation intensity of fatigue damage in the tool surface layer with repeated contact exposure to the material was studied at the original installation for test-a)

b)

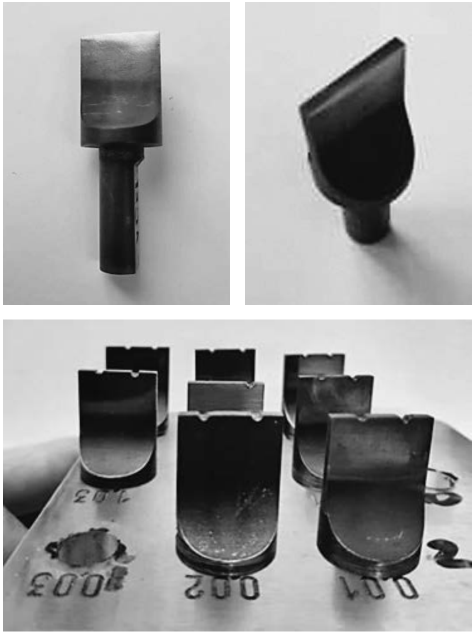


Figure 1 Samples shape: a - initial shape; b – after test

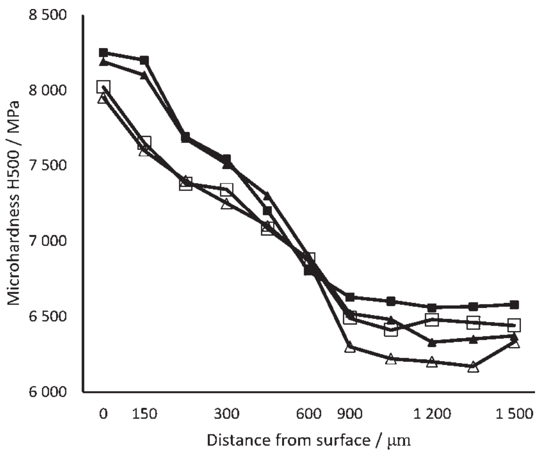
ing for contact fatigue and wear. The installation provides contact loading of the end surface of the flat part of the sample due to its rolling over the working surface of the disk counterbody with a linear velocity of 0,035 m/s. To simulate contact interaction during friction without slippage, a counterbody in the disk form is mounted on a ball bearing in the stem holder, and a sample with a flat working surface is mounted in the cell of a rotating faceplate. The movement of the sample along a circular trajectory when encountering a spring-loaded rod on which the counterbody disc is fixed causes it to rotate, excluding slippage on the contact surfaces. At the lower point of the trajectory, the working part of the sample is dipped into a pallet with a technological lubricant "Rosoil-SHOCK" TU 0258-001-06377289-94. The counterbody material is P6M5 steel with a hardness of 64 - 65 HRC. The width of the disk counterbody and the thickness of the working part of the sample make it possible to accurately calculate the contact surface area, and the loading scheme implements pulsating contact loading along the "strip". A similar approach is used in the study of wear of materials, both in rolling and sliding conditions in the contact zone [3].

The side surfaces of the working part of the samples are polished to study structural changes in the surface layer of the metal. The wear assessment of the sample is carried out by directly measuring the depth of the wear hole using an hour-type indicator with an accuracy of 0,01 mm. The obtained values are compared with the measurement results on an instrumental microscope at 50x magnification. Each batch subjected to the tests consists of 8 samples. Statistical processing of the test results was carried out by interval estimation of the mathematical expectation of the wear value using the Student criterion with a confidence probability of 0,9.

RESULTS AND DISCUSSION

As it was revealed by previous studies [4, 5], the wear resistance of medium-carbon alloy steels increases significantly when the surface layer is saturated with carbon. The tests carried out showed that in terms of wear resistance under sliding friction, carbonized steels of type 41Gr4, and 35GrMnSi4, are not inferior to such recognized carbide steels as X155CrMo12-1 and its analogues. The concept of the presented study takes into account that the initial 5KHV2S steel contains a sufficient amount of carbon to form a high-carbon matrix (martensite). At the same time, it is most acceptable to change the properties of the surface layer in terms of increasing contact endurance with a combined CTT, including simultaneous implantation of carbon and nitrogen. In our opinion, nitrocementation will not lead to the formation of large-scale colonies of carbide phases with their skeleton in the form of a brittle mesh. The results of volume-surface hardening of the samples are shown in the Table 1.

In all the studied cases, the final hardening resulted in a hardness of at least 48 HRC. At the same time, the hardness of the surface layer of the samples additionally subjected to nitrocementation was expected to be 58 - 61 HRC. The thickness of the layer of increased hard-



Forging in a tool that implements severe plastic deformation + nitrocementation: ■ - 8 hours, ▲ - 6 hours; Rolling + nitrocementation: □ - 8 hours, Δ - 6 hours

Figure 2 Distribution of microhardness over the cross section of nitrocemented layers of 5KHV2S steel after heat treatment

Table 1 **Influence of the modes of volumetric-surface hardening on the surface hardness**

Initial state	CTT modes			Hardness / HRC
	Processing type	Time / hour	T / °C	
forging	Without CTT			48 - 55
annealing				52 - 53
forging	Nitrocementation	6	880	58 - 60
forging		8		59
annealing		6		58
annealing		8		61

ness in all cases was no more than 0.5 mm. The hardness of the core of the samples subjected to CTT corresponded to the hardness of the steel that was not subjected to diffusion hardening (Figure 2).

Special attention should be paid to the differences in structural compositions, which in all the studied cases distinguish the surface layers of the samples, according to the results of the use of CTT. The use of nitrocementation ensures the productive formation of a two-phase composite material. Carbonitride inclusions are represented by two categories of formations – oblong grain boundary inclusions and secondary fine particles. The first of the designated objects are located at a short distance from the surface – about 30 - 50 μm (Figure 3). Their presence as inclusions, which can be sources of surface cracks, is localized in a narrow outer layer of the material. The second of the marked phases are revealed at the entire depth of the hardened layer. Their dimensions, not exceeding 1 μm, and rounded shape, as a rule, contribute to the strengthening of the composite material and increase its resistance to all known operational factors that affect the die tool.

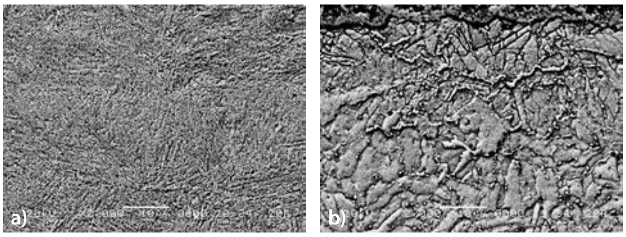


Figure 3 Structure differences of the surface layer of 5KHV2S steel formed by the CTT use: a - typical structure of the surface layer formed by volumetric hardening without CTT; b - typical structure of the surface layer formed by the inclusion of CTT in the process of volumetric-surface hardening

The expectation of increased resistance to contact wear, and is the main purpose of the hardening. The claimed research methodology allowed us to identify the maximum amplitude of the operational use of 5KHV2S steel, after volumetric surface hardening without the CTT use. As can be seen from Figure 4, when a pulsating contact stress with an amplitude of 970 MPa was applied to the sample surface, the maximum wear at the level of 0,6 mm was reached by 25 000 test cycles. The maximum wear value is accepted on the basis of the maximum possible tolerances that are applied to stamping of ferrous and non-ferrous metals produced by cold volumetric stamping methods. Special attention should be paid to the analysis of the difference between the indicators of wear resistance, revealed as a result of the use of pre-forging of workpieces in a tool that implements severe plastic deformation. The use of pre-forging in a tool that implements severe plastic deformation has shown a significant increase in operating time for failure. In addition, the wear curve obtained during the testing of forged samples differs in a fairly

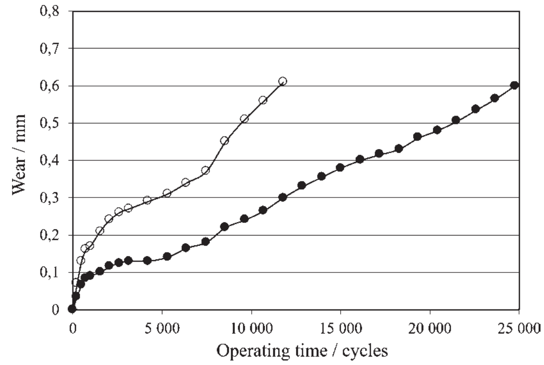


Figure 4 Wear curves of 5KHV2S steel at the amplitude of the effective contact stress of 970 MPa, the hardening of which did not include CTT: ○ - without pre-forging in a new tool, ● - with pre-forging in a new tool

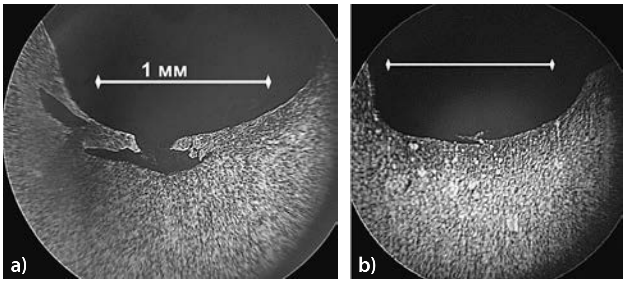


Figure 5 Contact strip of 5KHV2S steel samples that were not subjected to CTT at the final stage of testing with a pulsating contact stress with an amplitude of 970 MPa: a - without pre-forging in a new tool; b - with pre-forging in a new tool

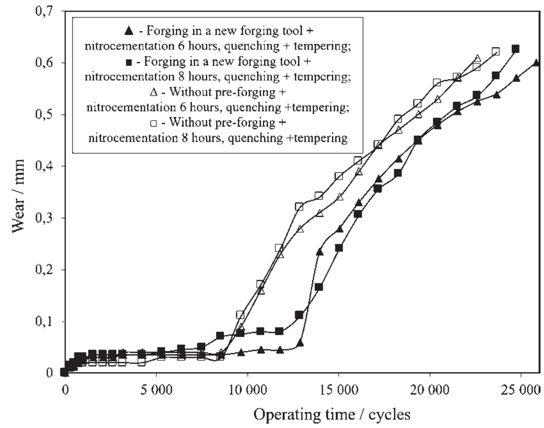


Figure 6 Wear curves of 5KHV2S steel samples under various modes of hardening treatment and the amplitude of the pulsating contact stress of 1 100 MPa

straight section, which begins with 5 000 test cycles. The mechanism of contact wear of forged samples was characterized by fine-scaled detachment, without the formation of deep subsurface cracks. For comparison, the contact surface of the samples that were not subjected to preliminary forging, at the last stages of testing, was destroyed by sufficiently deep cracks of contact fatigue (Figure 5).

Tests of samples additionally reinforced with nitrocementation showed their complete superiority in all indicators. As can be seen from Figure 6, along with the increased amplitude of the pulsating contact stress up to

1 100 MPa, a qualitatively different wear mechanism has been achieved.

At the initial stage of testing, areas of precision resistance of the surface layer of the composite material were obtained. For samples that were not pre-forged in the new forging tool, the period of precision durability was 8 500 cycles, and in the case of using pre-forging in the new forging tool, it increased to 12 900 cycles. In our interpretation, the period of precision resistance is considered to be the behavior of the surface layer of metal, in which, after the initial stage of run-in, a long period with minimal wear intensity occurs. It can be seen that the amount of wear (the depth of the wear hole) during this period did not exceed 0,1 mm.

CONCLUSIONS

The study of the effect of pulsating contact stresses on the surface layer of 5KHV2S steel showed that the specified material significantly exceeds economically alloyed structural steels of type 41Gr4, and 35GrMnSi4, which are close in carbon content. It is shown that without hardening of the surface layer, only due to its own wear-resistant characteristics, the alloy 5KHV2S is capable of satisfactory operation when a pulsating contact voltage with an amplitude of 970 MPa is applied to its surface. The mechanism after volumetric hardening – quenching + low-temperature tempering, is characterized by an almost linear pattern. The results were obtained taking into account the additional positive effect of the preliminary thermomechanical processing of the workpiece – forging in a new forging tool that implements severe plastic deformation in the entire volume of the deformable metal. This operation (forging in a new forging tool), introduced into the technological process of volumetric hardening, made it possible to increase the wear resistance of the alloy by 2 times.

The most significant achievement in the field of the stated goal was obtained due to the hardening of the surface layer by nitrocementation carried out before quenching and tempering. The technology of volume-surface hardening, including forging in a new forging tool that implements severe plastic deformation, CTT, quenching and low-temperature tempering provided a two-factor positive effect: the amplitude of the pulsating contact voltage, at which satisfactory operation of the tool for cold volumetric stamping is possible, can be increased to 1 100 MPa; the period of operation during the first 13 000 loading cycles, can be considered as a period of precision tool durability, with a maximum wear of the working surface of not more than 0,1 mm.

Acknowledgments

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Note: Translated by D. Rahimbekova, Temirtau, Kazakhstan