INFLUENCE OF THE DEFORMATION MODE ON THE FORMATION OF NANOSTRUCTURE, SURFACE RELIEF AND WEAR RESISTANCE OF STEEL 40KH

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Abstract

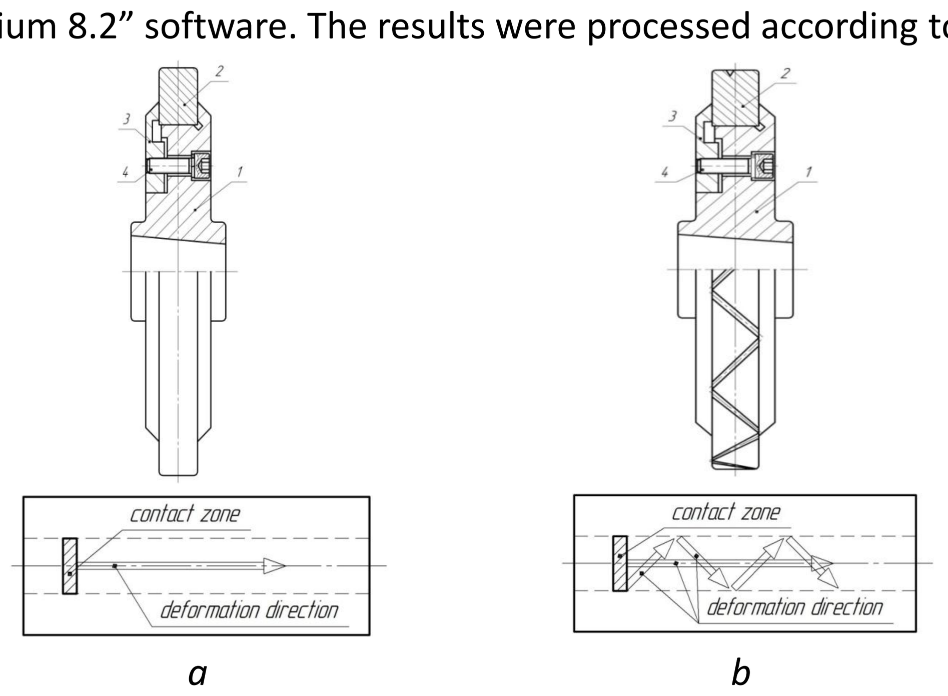
The effect of the deformation mode has been studied; it is realized by various hardening tools during the formation of a surface nanocrystalline structure on steel 40Kh by mechanical impulse treatment on the relief of the obtained surface layer, physical and mechanical properties, coefficient of friction and wear resistance under dry friction conditions. It is shown that the implementation of a simple shear mode with a special hardening tool forms a favorable surface relief, reduces the grain size and friction coefficient, increases the depth of the hardened layer, microhardness and wear resistance of the nanocrystalline surface layer on steel 40Kh.

Introduction

In recent decades, technologies for the creation and study of the properties of nanomaterials have been intensively developed. One of the most common methods for the formation of surface nanocrystalline structures (NCS) is severe plastic deformation (SPD). Thus, volumetric and surface NCS are formed. The formation of surface NCS is technologically simpler and, therefore, more widespread. One of the methods for the formation of surface NCS is mechanical impulse treatment (MPT), in which the source of SPD is high-speed friction. MPT increases wear resistance, contact and corrosion fatigue and reduces hydrogen permeability. During SPD, the structure is fragmented to the nanoscale. It is shown in this work that multiple transverse slip is a simple and effective mechanism of multiplication of dislocations, which leads to the formation of a dislocation line of great length, passing from one parallel plane to another. To implement this mechanism, we have developed a special hardening tool with inclined slots for multidirectional (with different modes) deformation for the formation of surface NCS. Such a tool makes it possible to form a structure with a higher density of dislocations, and, consequently, with a smaller grain size on the surface and a greater depth of the hardened surface layer. In addition, the surface roughness is reduced and its relief improves. Therefore, the aim of the work was to study the structure, surface relief, coefficient of friction and their effect on the wear resistance of heat-treated steel 40Kh and with a surface NCS formed by two tools under dry friction conditions.

Materials and Methods

Microhardness studies were carried out on cylindrical samples 25 mm in diameter and 100 mm in length made of 40Kh steel after MPT. The wear resistance of the samples was studied under dry friction according to the ring-insert scheme on an SMC friction machine with a specific load of 1 MPa, sliding speeds of 1 and 2 m/s. The diameter of the ring made of 40Kh steel is 45 mm. The inlays were made of gray cast iron SCH-20. Ring specimens were examined after quenching and tempering at a temperature of 200 °C (HRC 52-54) for comparison and in the state of delivery after MPT with tools with a smooth working surface (Fig. 1a) and with multidirectional grooved grooves (Fig. 1b) in the form of an equilateral a triangle with a side size of 4 mm. Heat-treated ring specimens were ground before testing. The MPT of the samples was carried out on the installation with tools made of steel 40Kh under the following conditions: the linear speed of the hardening tool is 60 m/s, the rotation frequency of the samples is 0.33 s^{-1}, the depth of the tool insertion is 0.35 mm, which corresponds to the pressure in the frictional contact zone 0.6 GPa, longitudinal feed 0.52 mm/rev. The width of the working part of the tools is 10 mm. Mineral oil with the addition of low molecular weight polyethylene for additional carburization was used as a technological medium for MPT. Experimental studies of surface topography were carried out on a “Talyscan 150” profilograph “Taylor Hobson”. Zones with a size of 6×6 mm were scanned on the treated surfaces of the samples using a diamond needle with a tip radius of 0.2 µm. The needle movement speed was 3000 mm/min, the step was 5 µm. The results were processed using the “Digital Surf Mountains Lab Premium 8.2” software. The results were processed according to the ISO 25178-26: 2012 standard. The amount of wear was determined by the weight loss over 6 hours. The samples were weighed on an analytical balance VLA-20g-M with an accuracy of ± 4 mg. For MPT, we used two designs of tools: with a smooth surface and with multidirectional grooves located at an angle of 45 ° to the vector of the rotation speed of the tool (Fig. 1a, b). The phase composition of the surface layers of steels after MPT was studied on a DRON-3 diffractometer-diffractograph in CuKα radiation (U = 30 kV, I = 20 mA) with a step of 0.05° and exposure at a point of 4 s. Diffraction patterns were processed using the CSD software package. Radiographs were identified from the JCPDS-ASTM card index cards. The grain size on the surface was determined by the X-ray method with the half-width of the peaks. The microhardness of the samples after MPT was measured on a PMT-3 microhardness meter at a load of 100 g.



a b

Fig. 1. General view of the used tools: *a* – with plane surface; *b* – with multidirectional inclined grooves: 1 – case; 2 – work disk; 3 – flange; 4 – screw.

Results

As a result of MPT, a martensitic structure was obtained after processing with a straight tool and a martensite-austenitic structure after processing with a tool with inclined multidirectional grooves. The grain size of the α-phase on the surface is, in the first case, 10.7 (Fig. 2, curve 1) and 8.7 nm (Fig. 2, curve 2) (Table 1).

Table 1

X-ray structural parameters of the α-phase of the surface layer of steel 40Kh after MPT with various tools: 1 - with a smooth surface; 2 - with inclined multidirectional grooves

№	$B_{(110)}$	$B_{(310)}$	L, nm	ε, %	$\rho\times10^{13}$, sm^{-2}	a, nm
1	0,682	1,552	10,7±0,8	0,077	0,48	0,28654
2	0,873	1,807	8,6±0,6	0,086	0,65	0,28642

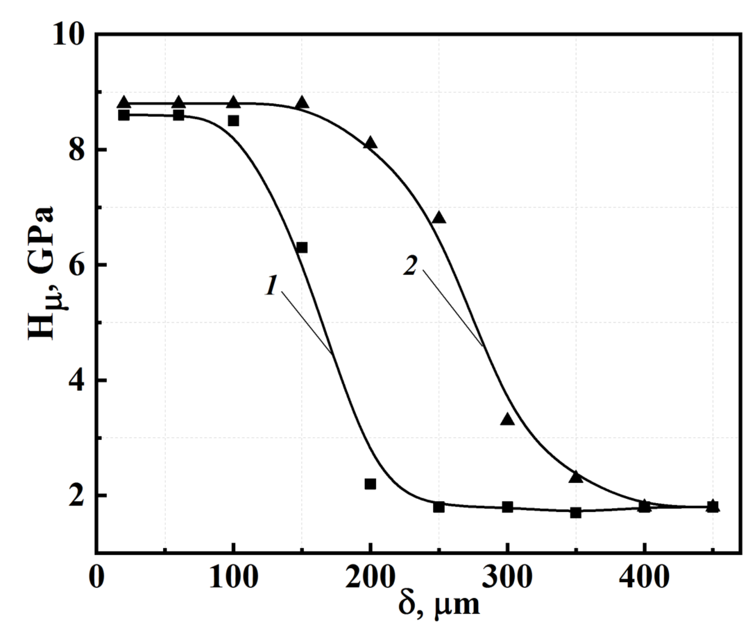
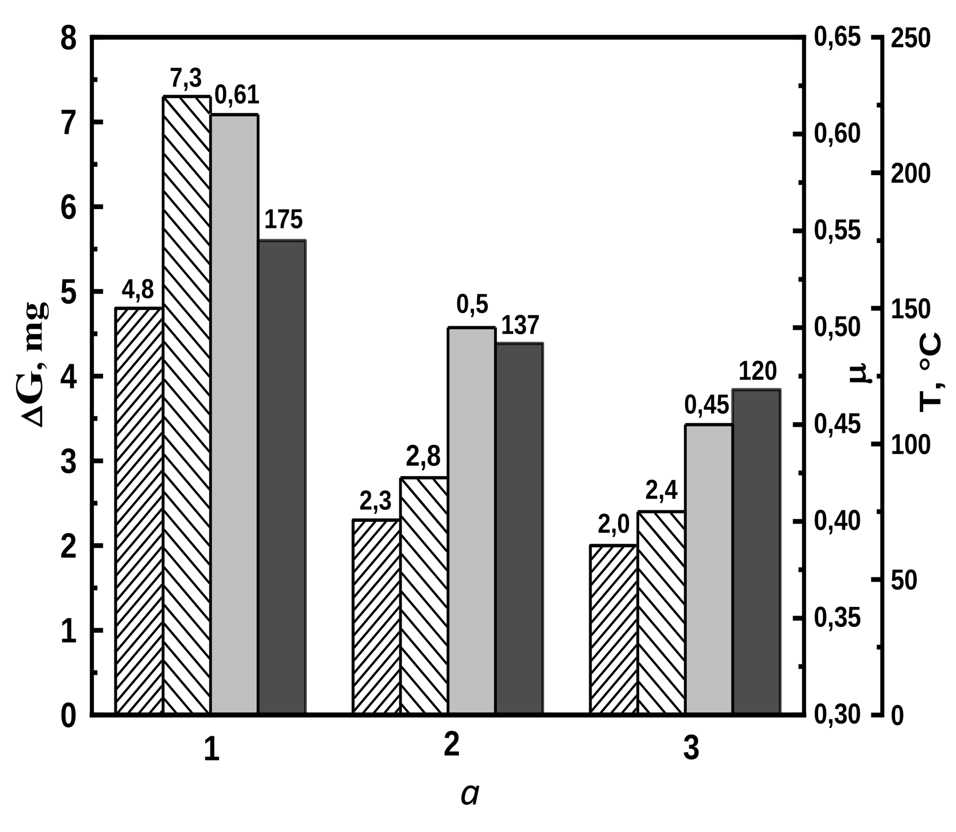


Fig. 2. Microhardness of the surface layer of 40Kh steel after MPT by different tools: 1 – with plane surface; 2 – with multidirectional inclined grooves.

Accordingly, the microhardness differs insignificantly, however, the depth of hardening when machining with a tool with inclined grooves increases to ~ 300 µm (Fig. 2, curve 2). Such an increase in the depth of the hardened layer is achieved due to the rectified deformation on the treated surface (Fig. 1b), namely, the conditions for the generation of dislocations and the dispersion of the structure are facilitated.



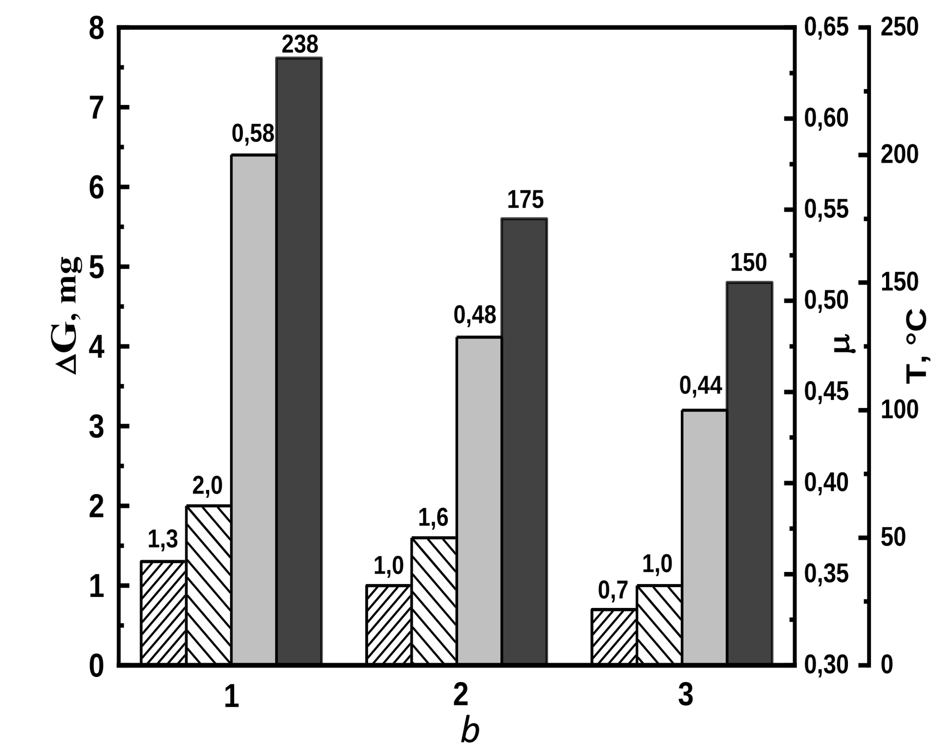


Fig. 3. Wear resistance of friction pairs steel 40Kh - SCH 20 after quenching and tempering at 200° C (1) and after MPT with a tool with a smooth working surface (2) and with multi-straightened grooved grooves (3) at a sliding speed of 1 m/s (*a*) and 2 m/s (*b*):
- loss of ring mass; - weight loss of the insert
- coefficient of friction;
- temperature in the frictional contact zone.

The wear resistance of specimens with surface NCS in both cases is higher than in heat-treated specimens due to an increase in the microhardness of the surface layer and a decrease in its friction coefficient (Fig. 3). An increase in microhardness is explained by the existing nanostructure and phase transformation during MPT in the surface nanocrystalline layer, and a decrease in the friction coefficient is explained by a change in the electronic configuration of the surface layer due to the pressure in the PC zone, which activates the s-d and s-d-f transitions of valence electrons. Such a change leads to a decrease in the friction coefficient due to an increase in the deposition of electrons of the d-orbitals into the metal bond, which leads to an increase in the interatomic interaction inside the metal, and, consequently, to its decrease on the sample surface. Correspondingly, the temperature in the FC zone of the NCL with the counter-body also decreases.

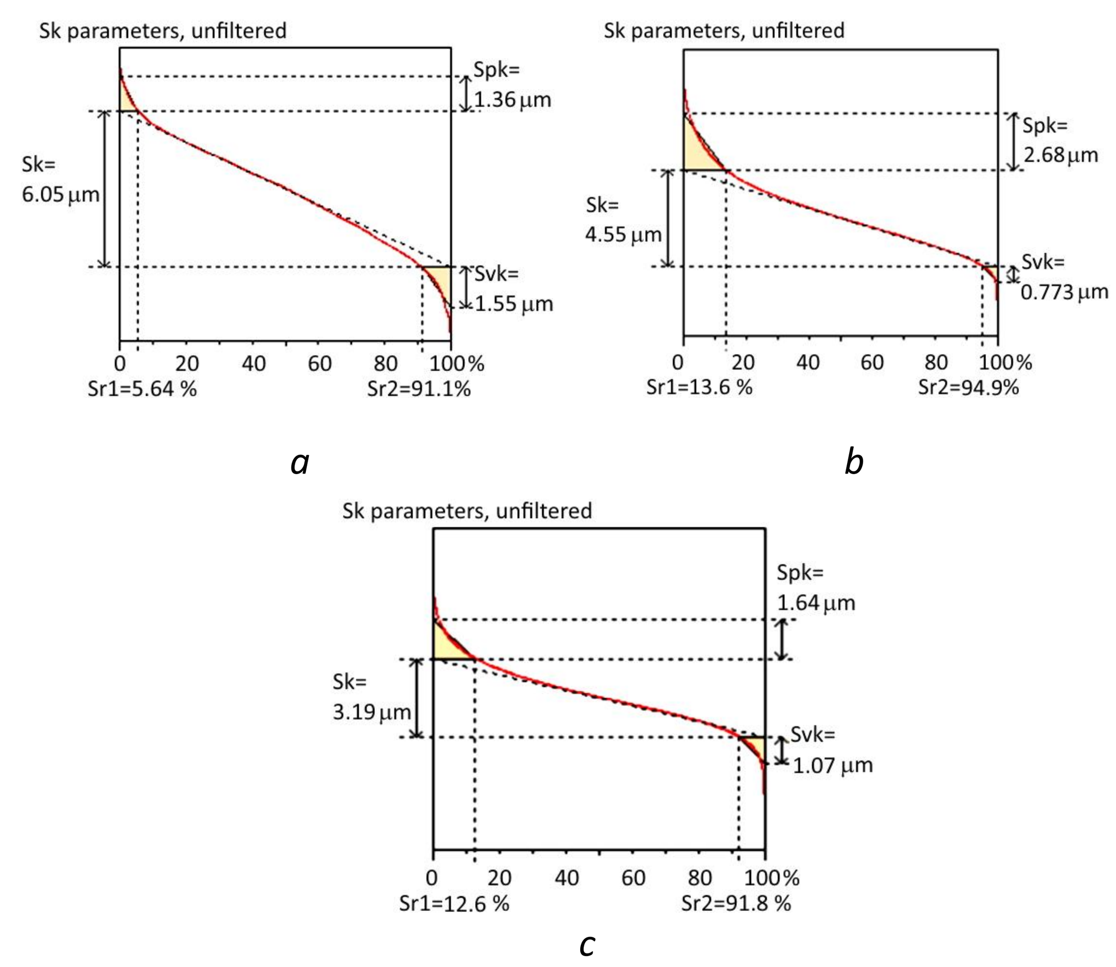


Fig. 4. Support curves of friction pairs steel 40Kh - SCH 20 after quenching and tempering at 200 °C (*a*) and after MPT with a tool with a smooth working surface (*b*) and with multi-straightened grooved grooves (*c*)

Analysis of the support curves of three pairs of friction shows a significant difference in their angle of inclination to the horizontal (Fig. 4). Reducing the angle is characterized by high wear resistance. It is clearly manifested by a gradual decrease in the S_k value from 6.05 µm to 3.19 µm. At the same time, the S_{pk} value characterizing the grinding process of surfaces in heat-treated specimens is small and amounts to 1.36 µm, and the S_{vk} value characterizing micro cavities for collecting wear products and oil in the case of oil friction is 1.55 µm and is the largest of all studied samples.

Conclusions

A hardening tool with multi-straightened grooved grooves forms a surface NCS with a smaller grain size, higher microhardness and a hardened surface layer depth by 100 microns more than a tool with a smooth surface. A tool that implements the multidirectional deformation mode, forming a surface relief with high wear resistance.

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