RESISTANCE OF SURFACE NANOCRYSTALLINE AND ULTRAFINE-GRAINED STRUCTURES TO WEAR AND CAVITATION EROSION DAMAGE

Y. B. Kyryliv[1], V. I. Kyryliv[2], B. R. Tsizh[3,4], O. V. Maksymiv[2]

[1]Lviv State University of Life Safety, [2]Karpenko Physico-Mechanical Institute of the NAS of Ukraine, [3]Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies, Ukraine, [4]Kazimierz Wielki University in Bydgoszcz, Poland

Abstract

One of the effective methods for the formation of surface nano- and ultrafine-grained structures is severe plastic deformation. Among them are mechanical impulse treatment (MPT) and vibration-centrifugal hardening (VCH). During MPT, a nanocrystalline structure with a high microhardness up to 8-12 GPa and a depth of up to 500 μm adjustable by processing modes is formed. VCH increases contact stresses in the contact zone, deforms and fragments the grain structure with high microhardness (7-9 GPa) and an increased depth of the hardened layer up to 5 ... 6 mm. This makes it possible to carry out additional finishing operations for high precision surfaces. In this work, the wear resistance and resistance to cavitation-erosion destruction of such structures are investigated. It is shown that nano- and fine-grained surface structures have a reduced coefficient of friction, which is obviously associated with a change in the electronic configuration caused by high compressive stresses in the grains. Their advantages in comparison with traditional methods of heat treatment are reflected.

Introduction

The NCS surface can be formed by mechanical impulse treatment (MPT) of metal, based on high-speed friction between the component being processed and a special metal tool. A special technological medium is fed into the friction zone in order to play two roles: (a) alloying the surface layer with chemical elements present in the medium due to its thermal destruction in the contact zone and intense mass transfer and (b) structural and phase transformations in the material, providing it fast cooling.

Previous studies have shown that NCS and UFGS can be formed, in particular, using severe plastic deformation (SPD) of the surface. One of such methods is vibration-centrifugal hardening (VCH). In these works, it was shown that VCH, due to the significant mass of the hardening tool, forms an UFGS of high microhardness and significant (up to 6 mm) depth.

The aim of this work is to study the wear resistance and resistance to cavitation-erosion destruction of nanocrystalline and ultrafine-grained structures obtained by MPT and VCH and their comparison.

Materials and Methods

The material for the study was chosen steel 40Kh. MPT was applied to specimens of two geometries: flat and cylindrical (Fig. 1). Flat samples for measuring microhardness were turned from a rod 25 mm in diameter. The bar was forged to a strip size of 4 × 32 mm, annealed at a temperature of 860 °C, after which specimens with a size of 2 × 20 × 30 mm were processed. MPT was applied to the samples from both sides on an SPC-20 surface grinder under the following processing modes: tool rotation speed 50 m/s, linear velocity of stage movement 0.0017 m/s, cross-sectional tool advance 0.5 mm on a double stage movement, depth of run 0.3 mm (the value characterizes the force of pressing the tool against the processed sample). Cylindrical specimens (rings) with a diameter of 40 mm and a thickness of 10 mm for the study of wear resistance were made from a bar and processed by MPT on a slightly modified grinding machine 1K62 using the same technological media for carburizing in the following modes: tool rotation frequency 50 m/s, the rotation speed of the processed sample is 0.04 m/s, the depth of the run is 0.3 mm.

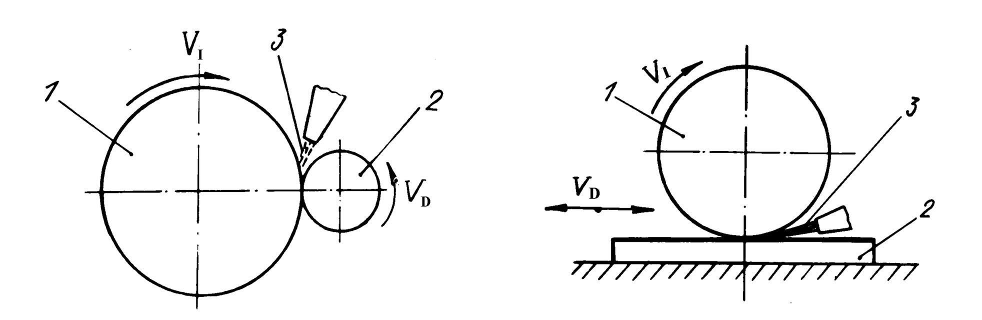


Fig. 1. MPT scheme of cylindrical (a) and flat (b) surfaces: 1 - hardening tool; 2 - work piece; 3 - technological media

Samples were made from it - rings with an outer and inner diameter of 75 and 60, respectively, and a width of 20 mm. Hardened rings of the same steel for comparative studies of wear resistance reached a hardness of HRC 52-54. For the study of CED, rectangular samples of 14 x 12 mm 6 mm thick were cut from the above rings, in which the surface was hardened by VCH. Strengthening was carried out on a special vibration-centrifugal reinforcing installation (Fig. 2) with a special massive tool with balls 13 mm in diameter fixed in it. The installation provides vibrations of a certain amplitude and pumping of the tool and its movement along the machined cylindrical surface. Samples were fixed on a mandrel. Processing was carried out with the following parameters: amplitude of oscillations A = 5 mm; oscillation frequency f = 24 Hz; mass of the working tool m = 3.5-7.5 kg processing time t = 12-36 min; eccentricity ε = 10 mm.

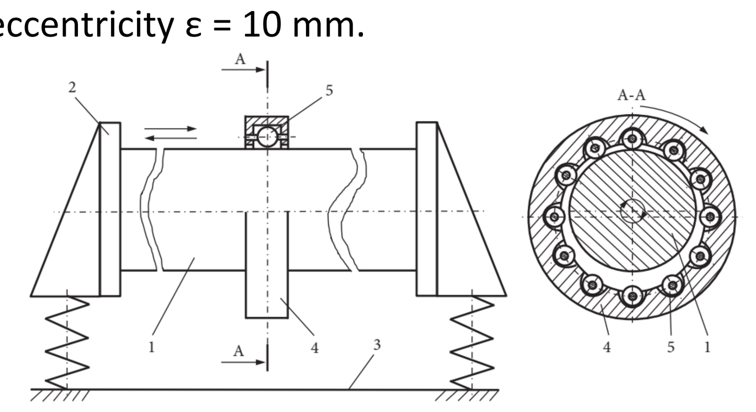


Fig. 2. Scheme of VCH of external cylindrical surfaces: 1 - sample; 2 - bracket; 3 - the general platform; 4 - tool; 5 - balls

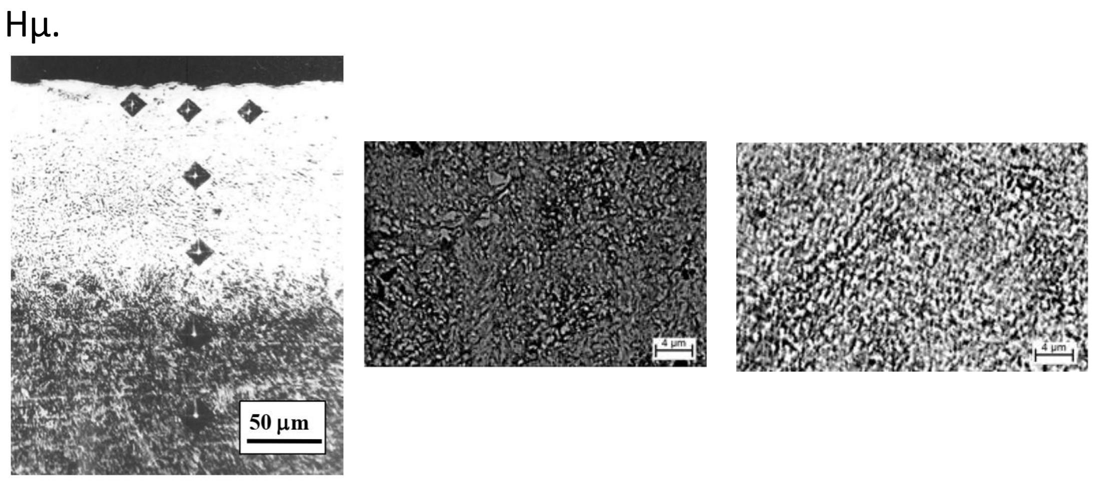
The microhardness and the hardening depth were measured on a PMT-3 instrument according to the standard procedure with a load on the pyramid of 100 g. The microstructure was examined using an EVO 40XVP scanning electron microscope.

A study of wear resisting properties and the determination of the friction coefficient was carried out on a MI-1M friction machine using a ring-liner scheme in an oil and oil-abrasive environment. The sample rings had the diameter of 75 mm. Slavol M - 3042 TU 13932946.015-96 with 0.1% by weight of quartz sand (up to 40 μm size) was used as an oil at 2.0 MPa and a sliding speed of 0.9 m/s. Weight loss for an appropriate period of time (2 hours) was assumed as the criterion of wear. Weighing of the samples was carried out on analytical scales VLA-20g-M with an accuracy of ± 4 mg.

Erosion losses were measured by the gravimetric method. Before and after cavitation erosion tests, the samples were washed in acetone, then in ethanol, then dried, and only after that they were weighed on an VLA-200M analytical balance with an accuracy of ± 0.00005 g.

Results

The metallographic studies of the cross-section of the flat specimen in depth from the surface revealed the strengthened surface layer as the unetched area (so called «white layer») (Fig. 3a). It can be visually observed that the size of microhardness indentation imprints in the strengthened layer were smaller than in the matrix material which points to its higher microhardness. The quantitative assessments of Hμ in a depth δ from the surface and from the side of section (Fig. 1a) showed that microhardness varied from maximal value ~ 9.4 GPa on the surface to 2.18 GPa in the matrix material, which was in 3 times less (Fig. 4). Thickness of the strengthened layer was ~ 150 μm and it corresponded with the thickness of the unetched area revealed at the metallographic analysis. Such correspondence points to responsibility of the unique structure of strengthened layer for its mechanical property Hμ.



a b c

Fig. 3. The microstructure of 40Kh steel after MPT and VCH at depths: a – unetched area, b – 100 μm, c – matrix structure of 6 mm

After the VCH, the microstructure is highly fragmented near the surface at a depth of 100 μm (Fig. 3b). The grains are fragmented unevenly by separate blocks. At a depth of 1000 μm, the picture is similar, and the distribution of grain size decreases, apparently due to a more even distribution of deformation during the impact of the balls' surfaces, and smoothly passes to the initial matrix structure (Fig. 3c).

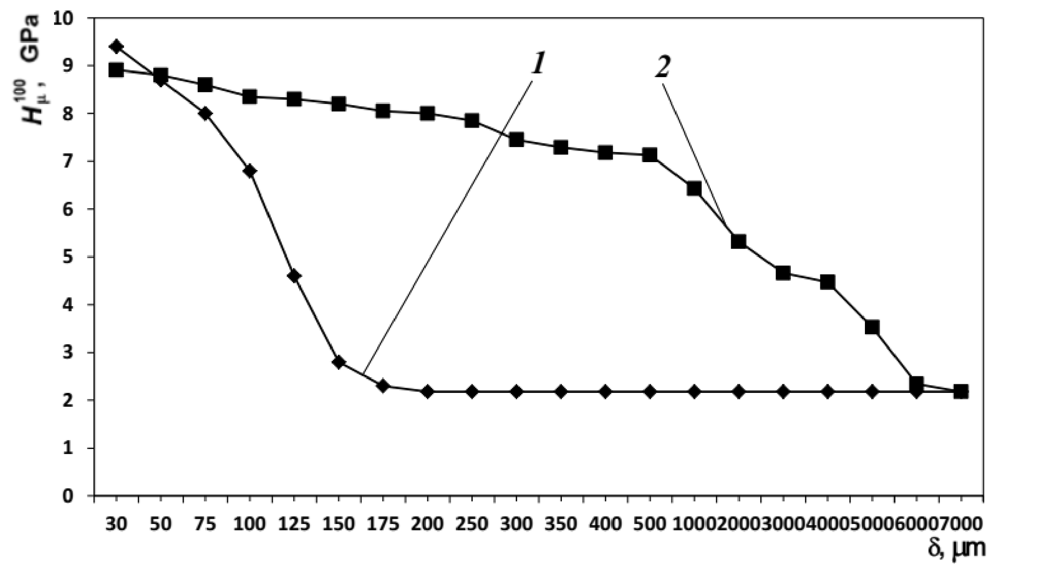
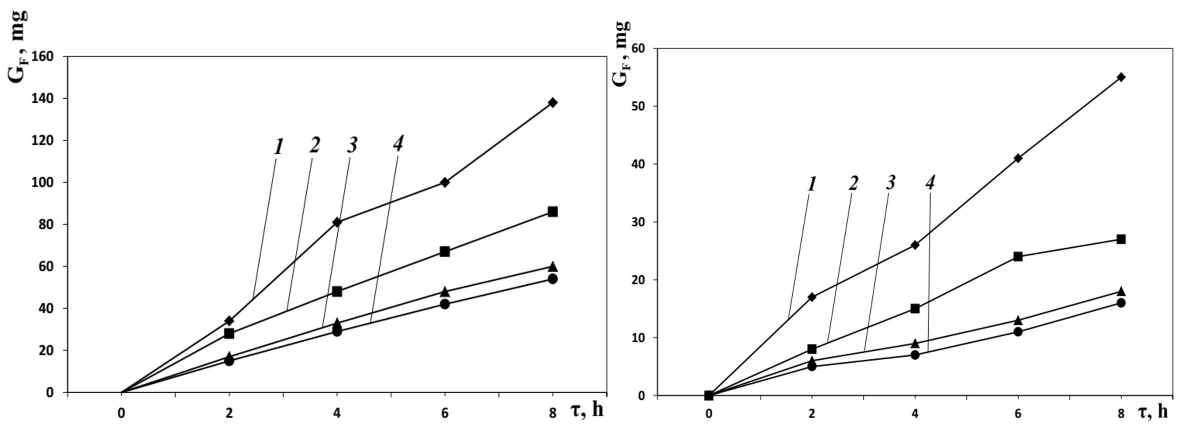


Fig. 4. Microhardness of the hardened steel layer 40Kh after various processing methods: 1 – MPT; 2 – VCH

According to X-ray analysis, the steel after MPT had a microstructure, which consisted of pure ferrite α-Fe with grain size ~ 60 nm. It should be noted that MPT causes heating of surface layers to temperatures above the temperature of phase transformations.

The microstructure after explosive attack at a depth of 100 μm near the surface is highly fragmented (Fig. 3b). The grains are fragmented unevenly in separate blocks. With optimal processing conditions m = 4.5 kg; τ = 28 min, hardening depth δ = 6 mm and microhardness of 8.9 GPa (Fig. 4), a single-phase structure of the ferrite class (Fig. 3b) with a grain size on the surface up to 190 nm was obtained, a high dislocation density of 0.84 × 10^{12} cm^{-2}.



a b

Fig. 5. Wearing kinetics for friction pairs made of 40Kh - ShKh15 steels after technological processing methods (a - ring; b - insert) under a load of 2 MPa in an oil-abrasive environment: 1 - normalization; 2 - quenching with low tempering (200 ˚C); 3 - VCH; 4 – MPT

The surfaces of the NCS and UFGS samples obtained under optimal conditions were examined for wear resistance. A uniform hardened layer on the surface of the specimen increases the wear resistance under conditions of oil-abrasive wear (Fig. 5) by 1.4 times or more, respectively. The wear resistance of unstable inserts also increases due to a decrease in the friction coefficient of a pair from 0.18 (for hardened specimens) to 0.07 (for specimens with surface UFGS). The main factors causing an increase in wear resistance are increased microhardness and a low coefficient of surface friction with NCS and UFGS.

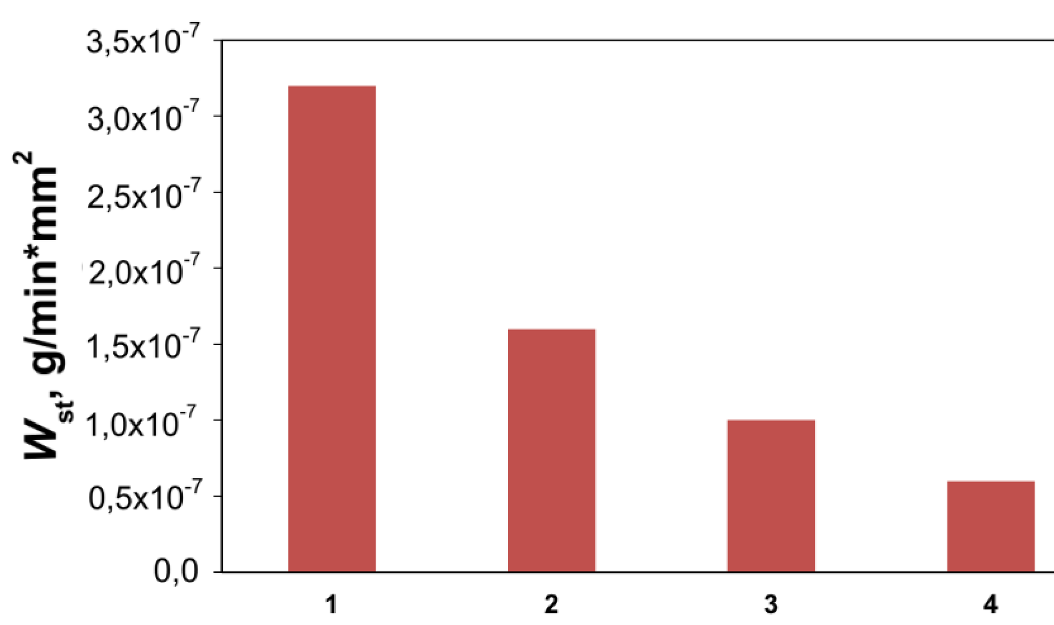


Fig. 6. The dependence of the stabilized speed of the CED on the amplitude of testing 70 μm of samples of steel 40Kh after technological processing methods: 1 – normalization; 2 – quenching with tempering at 200 °C; 3 – VCH (m = 7.5 kg, τ = 28 min); 4 – MPT

The characteristics of the CED - resistance of steel 40Kh after different technological methods of smelting differ significantly (Fig. 6). According to the criterion of the stabilized CED velocity Wst (Fig. 6), MPT and VCH turned out to be the most effective with the mode m = 7.5 kg, τ = 28 min. HF in modes: m = 3.5 kg, τ = 20 min; m = 4.5 kg, τ = 28 min is ineffective. These modes ensure the achievement of the maximum microhardness at the indicated mass of the tool (m = 3.5 kg and 4.5 kg) due to the achievement of a high defectiveness of the surface layer.

Since it is believed that CED occurs by the micro-fatigue mechanism, the presence of an inhomogeneous surface with significant defectiveness of a corrosive surface greatly facilitates the destruction of the material. This is due to the relatively insignificant thickness and microhardness of the hardened layer in comparison with the depth of CED effect (Fig. 8, column 1).

From this, we see that the MPT and VCH technologies increase the durability of machine parts operating in CED conditions. More effective for VCH are modes characterized by a slightly lower microhardness, but higher corrosion resistance. Moreover, as can be seen from Fig. 8, the cavitation-erosion resistance at a stabilized CED rate increases by 2 or more times.

It has been established that the highest resistance to cavitation-erosion destruction is observed at a slightly lower microhardness of the surface and its higher values in depth.

Conclusions

1. The MPT technology provides the formation of a nanocrystalline structure, and the VCH forms an ultrafine-grained structures. The microhardness of the nanocrystalline structure is somewhat higher than the ultrafine-grained structures.
2. After VCH, the depth of the hardened layer is much greater, which makes it possible to carry out finishing operations for high-precision parts.
3. Both methods provide high wear resistance and CED resistance in comparison with traditional heat treatment, which is associated with high surface hardness.

Contact information Kyryliv Y. B., e-mail: yaroslav_kyryliv@ukr.net