CONTROL OF HYDROGEN CHARGING INTENSITY IN THE SUBSURFACE LAYERS OF STEEL PARTS BASED ON THE ANALYSIS OF WEAR PARTICLE IMAGES

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The theses present selected results related to the diagnostics of the condition of materials in components exposed to long-term hydrogen influence. One of the promising directions of this scientific and practical approach is the development and implementation of computer vision methods for detecting signs of degradation and damage based on the analysis of surfaces and wear particles.

Keywords: hydrogen charing, steel, wear particles, computer vision

Introduction. The development of modern technologies is closely linked to the implementation of hydrogen energy as a key element of the energy transition. At the same time, the influence of hydrogen on the properties of steels – particularly their durability, corrosion resistance, and mechanical stability – requires thorough fundamental and applied research. One of the promising directions for assessing the condition of structural elements, machine parts, and mechanisms during long-term operation is the analysis of wear products, changes in surface layers, and diagnostics of material degradation processes. These approaches are becoming especially relevant in the context of digital technology development and the implementation of Industry 4.0 and 5.0 concepts, which enable the integration of intelligent monitoring systems into production and energy processes [1–11].

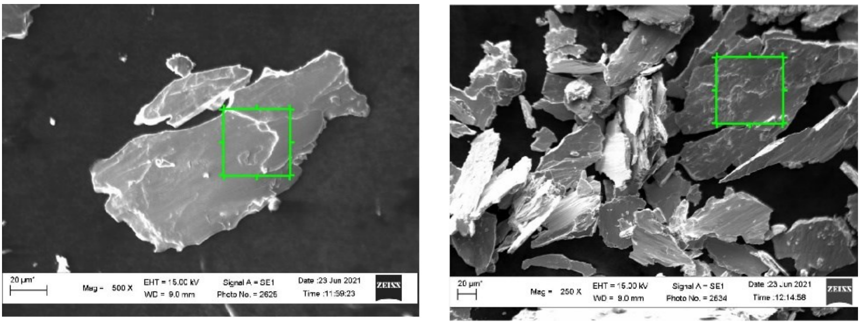
Materials, equipment and test methods. The wear intensity of non-hydrogenated and hydrogenated samples of cold-deformed high-nitrogen manganese steels under dry friction conditions was studied, along with the characteristics of their friction surfaces and the morphology of the wear products. The high-nitrogen steel samples were hydrogenated electrolytically at a current density of 0.5 A/cm² in a 26% sulfuric acid solution for 3 hours. The purpose of the electrolytic hydrogenation of the alloys was to saturate their surface and subsurface layers with hydrogen and to conduct tribological tests simulating friction under conditions of maximum hydrogen exposure.

Wear resistance was determined using a CMT1 (2070) friction testing machine. The sliding speed of the lower roller was 1480 RPM, and that of the upper roller was 1240 RPM, resulting in 15% slip. The lower roller (∅ 42 mm) was made of 1.0503 (DIN) steel (HRC = 60) (analogous to steel grade 45), while the upper roller was made of high-nitrogen steel: DDT 68 with a hardness of 45–52 HRC. The linear speed of the upper roller was 2.27 m/s, and that of the lower roller was 3.08 m/s. Under dry friction conditions, the applied load ranged from 200 to 600 N. The chemical composition of the investigated alloys is presented in reference [2].

The microstructural parameters and friction surface features were examined using an EVO-40XVP scanning electron microscope equipped with an INCA Energy 350 microanalysis system at the Center for Electron Microscopy and X-ray Microanalysis of the G.V. Karpenko Physico-Mechanical Institute of the National Academy of Sciences of Ukraine.

To determine the phase composition of the steel microstructure, the sizes of wear products and surface damage on friction surfaces, as well as to perform 2D and 3D reconstructions of wear surfaces, the software packages TOUP VIEW 3.7 and Gwyddion 2.62 were used.

Results of the investigations. An analysis of the morphology of wear products was conducted before and after hydrogenation (Fig. 1), and 2D and 3D reconstructions of the wear surfaces were performed. In addition, specific areas of wear particles were examined using a proprietary patented computer program (Fig. 2) [11].



a b

Fig. 1. Wear particles: before hydrogen charging (a); after hydrogen charging (b). The green color outlines the square whose area was studied using a computer vision system.

The developed computer program (CP) can be used to monitor the fractography of wear particle surfaces and, accordingly, to control changes in surface morphology. This, in turn, makes it possible to predict the operational stability and durability of the tribological assembly.

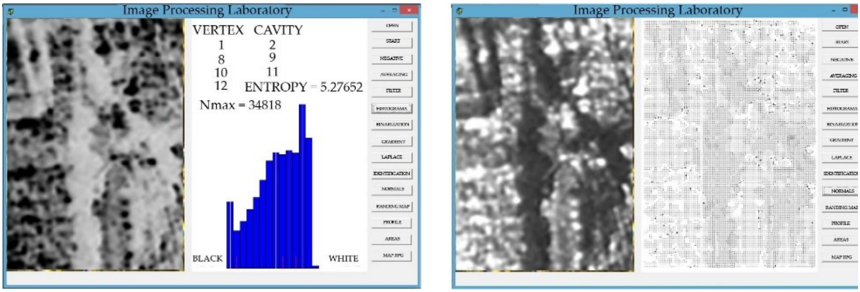


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Fig. 2. Examination of digital images of the non hydrogen charging using the developed CP: histogram construction operation (a), the operation of constructing normal (b).

Among the data calculated by the program, we highlight VERTEX, CAVITY, Nmax, and ENTROPY [11].

We obtained several dozen high-quality photographs of wear particles taken under various conditions, which can be used to expand the research horizons using computer vision methods to obtain various correlations.

We can also expand the possibilities of wear particle research by writing additional scripts, for example, in the Python language.

Conclusion. The analysis of the conducted studies confirmed that hydrogen saturation of high-nitrogen steels significantly alters the morphology of wear products and the nature of surface damage, indicating the activation of physicochemical processes under the influence of hydrogen. The comparison of wear before and after hydrogenation revealed a substantial difference in microstructure, particle size, and the degree of local damage.

The use of computer vision made it possible to perform a quantitative assessment of wear particle morphology parameters (VERTEX, CAVITY, Nmax, ENTROPY), which opens up prospects for automated real-time monitoring of the technical condition of tribological assemblies. The developed computer program provides fractographic analysis and 2D/3D surface visualization, and also allows for extended functionality through the integration of external scripts, including those written in Python.

Thus, the integration of computer vision methods into the diagnostics of machine components subjected to prolonged friction in a hydrogen environment is an effective tool for improving reliability, predicting service life, and ensuring the safe operation of structures under the conditions of advancing hydrogen energy and the implementation of Industry 4.0/5.0 digital technologies.

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