ANNOTATION

dissertations for the degree of Doctor of Philosophy (PhD) on the specialty 6D072300 - «Technical Physics»

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by topic: **«Change of structure and properties of wheel steel surface under electrolytic-plasma surface hardening»**

The dissertation is devoted to the study of the influence of electrolytic plasma surface hardening on structural-phase states, tribological and mechanical properties of steel brand 2, which is widely used for the manufacture of wheel pairs of railway transport.

Relevance. The development of the modern engineering industry is connected with the development of new materials, the introduction of innovative technologies and equipment, including the creation of new ways to improve the performance properties of machine parts and mechanisms. The main operational properties of machine parts - wear resistance, strength, corrosion resistance are largely determined by the condition of their surface layer, determined by the manufacturing technology as, 60-80% of mechanical engineering products fail due to surface damage during wear. For many parts of railway transport, construction, road and agricultural machinery, metallurgical, press equipment durability and reliability of work is limited by the main factor - wear and contact fatigue defects of working surfaces. Wear is accompanied by a change in the shape, size and condition of the surfaces of the parts, which leads to a decrease in the functional properties and productivity of technological industrial equipment, an increase in the probability of failure. Steel and cast iron continue to be the material of most mechanical engineering products. Therefore, improving the wear resistance of iron alloys is one of the most important and topical tasks of technical physics.

There are quite a number of different technological methods to improve the quality of the parts surfaces. The most common ones are galvanic and chemical coating methods, surfacing, sputtering, chemical-thermal treatment, high frequency surface quenching, surface quenching with concentrated energy streams (plasma, electron-beam and laser) etc. Among them, the most promising method of surface hardening of iron alloys is the surface hardening of concentrated energy streams. However, the widespread introduction of some methods of surface hardening concentrated flow of energy, namely laser and electron-beam, is constrained by the high cost and complexity of the equipment, its reliability and performance, the need to use a vacuum, special rooms with special requirements, the need for qualified maintenance, high operating costs. Therefore, for wide implementation on its techno-economic indicators and the results of comparative analysis recommended a method of plasma surface hardening, which is devoid of the above shortcomings. Plasma surface hardening has been successfully developed in recent years and is increasingly used in various industries, in particular for the heat treatment of railway parts (Freight wagon Friday, superstructure and trolley side frame, bandage, etc.).

Being one of the varieties of plasma hardening - electrolytic plasma surface hardening recently developed and intensively studied. This method is characterised

by lower energy consumption, simpler process equipment and larger area dimensions. The advantages of the method are that the process is sufficiently large and the parts can be hardened with a large mass and complex profile, and the degree of hardening is comparable to plasma hardening.

It is common knowledge that the lifetime of steel parts is determined by their performance (ranging from the chemical composition of the material to the condition under which a part is to be operated), most of which is directly structurally dependentphase state of the material. Studies of structural and phase transformations in wheeled steel during plasma surface hardening are scarce and do not fully address structural issues. At the same time, in the literature there is no data on the treatment of wheel steel with electrolyte-plasma hardening, which requires complex experimental work to determine the further application of this method for reinforcing wheel pairs. At the same time, despite the number of electrolytic plasma treatment of iron alloys, the quantitative characteristics of the fine steel structure after electrolytic plasma surface injection have not been sufficiently studied.

In connection with the above, the topic of the dissertation is devoted to the development of the method of hardening of wheeled steel and the study of the regularities of the formation of the fine structure, phase composition and the physical foundations of the tribological properties of the strengthened surface layer at electrolyticplasma surface hardening steel grade 2, is current.

The aim of the dissertation work is to develop a method of electrolytic plasma surface hardening, to select an optimal hardening mode providing an increase in mechanical and tribological properties and to further study the microstructure, phase composition and fine structure of toughened steel grade 2.

In accordance with the objective, the main objectives of the study were formulated:

1.To develop a method and an optimal mode of electrolytic-plasma surface hardening of the rail girder material made of a grade 2 wheeled steel;

2.To study the change of mechanical and tribological properties of the surface layers of steel grade 2 before and after electrolytic plasma surface hardening;

3.To study the features of the formation of structural-phase steel composition grade 2 at electrolytic-plasma surface quenching;

4.Quantitatively determine the parameters of thin structure of initial and hardened in electrolyte plasma steel grade 2.

The subject of the study is the phase composition, thin structure, mechanical and tribological properties of the modified steel layers of grade 2 after electrolytic-plasma surface hardening.

The object of the research is the steel grade 2 before and after electrolyte plasma exposure, electrolyte plasma processing technology.

Methods of research. According to the tasks used such methods of analysis: Raster electron microscopy (SEM); Transmission Electron Microscopy (TEM); X-ray Structural Analysis (XRD); microhardness measurements, wear resistance and corrosion resistance tests.

Scientific Novelty.

–The invention relates to a method for treating wheel steel by electrolytic plasma surface quenching in an aqueous electrolyte solution.

–New experimental data on the influence of electrolytic plasma surface hardening on structural and phase steel states of brand 2 have been obtained.

–For the first time the peculiarities of formation of thin structure of near-surface and transition layers of steel of brand 2 after electrolytic-plasma surface hardening were studied and quantitative characteristics of structural and morphological components were calculated.

Main provisions for protection:

1. Electrolyte plasma cathode heating in electrolyte from aqueous solution containing 10% carbamide $(NH_2)_2CO$ and 20% sodium carbonate Na_2CO_3, at 300 V and current density 10-12A/cm^2 results in a modified surface layer of wheeled steel with an increase in wear resistance of 2.5-3.8 times and an increase in hardness to 3.5 GPa.

2. In steel grade 2 after electrolytic plasma surface hardening batch, plate low temperature and plate high temperature martensite with bulk fractions of ~ 60%, ~10% and ~30%, respectively, as well as formed carbide particles of special type $M_{23}C_6$, located on the borders of martensitic crystals, with an average size of ~5 nm.

3. Electrolytic plasma surface hardening of steel grade 2 leads to changes of quantitative characteristics and parameters of thin surface layer structure: the density of dislocation increases from $2{,}1\cdot10^{10}$ cm^{-2} to $2{,}24\cdot10^{10}$ cm^{-2}, conditions $\rho > \rho_{\pm}$ and $\sigma_{Л} > \sigma_{\partial}$ are fulfilled, that prevent the formation of microfractures in the material.

Scientific and practical significance of the work.

The article shows the possibility of application of research results for surface processing of material of bandage of wheel pairs and other parts of railway transport in order to increase their operational properties, which is confirmed by patent 5365 RK IGC C21D 1/09 (2020/0348.2).

The results of the study of fine structure and properties of steel grade 2, parameters of the sub-structure revealed in the present work, having some influence on the surface hardening of steel, can be used as teaching material in the course of a lecture on the physics of condensed state, materials science and surface hardening of materials for the development of the theory of structural-phase transformations in steels (the act of introduction in the educational process from 25.01.2022 for the preparation of bachelors and undergraduates on OP «Technical Physics» NAO «VKTU them.D.Serikbayev»).

Relationship with research projects.

The dissertation work was done in D. Serikbayev East Kazakhstan technical university, S. Amanzholov East Kazakhstan university and in Tomsk State Architectural and Construction University as part of the implementation of the state budget project grant financing on the topic «Research and development of innovative technologies for obtaining wear-resistant materials for engineering products», state.reg. 0118RK00989, financed by the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan under the Agreement 197 dated 16.03.2018.

The personal contribution of the author consists in carrying out the majority of experimental and theoretical researches, processing of measurement results, their analysis on the basis of existing representations of the physics of condensed state and physical material science.

Credibility and validity. The research was carried out using proven research methods using modern equipment and innovative approaches. The discussion of the results at each stage of the study was reported at the scientific seminars of the department, and the results were presented at international and regional conferences, symposiums with the participation of leading specialists in the field. The results were validated by peer review in international periodicals and reports of international conferences included in the databases of Thompson Reuters and Scopus. The results of the research were also tested positively at the Patent Office of the Republic of Kazakhstan, on the basis of which the author obtained a patent for a useful model.

Approbation of the dissertation work. The results of the thesis were reported and discussed at 5 scientific and technical conferences and seminars, including:

1. International scientific and practical conference «XXXXVIIth Autumn Tribology School» (2019, Wroclaw);
2. 11th International Scientific Conference Chaos and structures in non-linear systems. Theory and Experiment» (2019, Karaganda);
3. VI International scientific and practical conference «Science and Education in the Modern World: Challenges of the XXI Century» (2020, Nur-Sultan);
4. XVII International scientific and technical conference of students, postgraduates and young scientists «Prospects of development of fundamental sciences» (2020, Tomsk);
5. XVI International School-Seminar «Evolution of defective structures in condensed environments» (2020, Barnaul).

In addition, the main results were reported and discussed at scientific seminars of doctoral students of the WCTU. D. Serikbayev.

Publications: 12 printed works including 2 articles in peer-reviewed foreign scientific journals with impact factor included in the database Scopus and Web of Science have been published on the basis of the thesis materials, 4 publications recommended by the Committee for Quality Assurance in the Sphere of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan and 5 works in the materials of the International and Republican scientific conferences and 1 patent on the useful model of the Republic of Kazakhstan.

Volume and structure of the dissertation. The dissertation consists of an introduction, 4 sections, a conclusion and a list of sources of 144 titles, contains 119 pages of the main computer text, including 61 drawings and 12 tables.