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SCIENTIFIC AND APPLIED ASPECTS OF ELECTROLYTE-PLASMA SURFACE STRENGTHENING OF CARBON STEEL PARTS

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Abstract

This article investigates the process of treating the surface of carbon steel parts using the electrolytic-plasma method. The study analyzes how this method improves the hardness, wear resistance, and corrosion resistance of the part surface. In addition, modern concepts of steel surface hardening, energy-efficient technologies, and their prospects for industrial application are highlighted. The research results demonstrate the effectiveness of the electrolytic-plasma method.

Keywords

carbon steel, electrolyte-plasma, surface hardening, hardness, wear, corrosion, advanced technologies, electrolyte-plasma nitriding

One of the main tasks at the current stage of the development of mechanical engineering and industry is the creation of energy- and resource-saving technologies, as well as mechanisms for improving the quality, reliability, and durability of the working parts of various machines and units.

The surface layer of machine parts, both during manufacturing and operation, is subjected to dynamic and cyclic stresses that lead to one or more elastic-plastic deformations, hardening or softening, and eventual failure. Wear of the working surfaces of parts often requires their complete replacement. This increases production costs due to high depreciation expenses.

The aim of the work: to study the structural-phase state, mechanical properties, and corrosion resistance of the modified surface layers of 12X18N10T steel after hardening under different EPO (electrolytic-plasma treatment) regimes.

1) to develop EPO technology to improve operational properties and to establish optimal steel processing regimes;
2) to study the patterns of changes in the structure and phase composition of the steel surface during electrolytic-plasma treatment;

3) to study the morphology of carbide and carbonitride particles formed as a result of EPO and the substructure of the modified surface layers of steel;

to determine the dependence of microhardness, wear resistance, and corrosion resistance on the EPO regimes;

As a result of solving the stated tasks, a significant contribution will be made to the physical foundations of chemical treatment of steels, particularly to the understanding of the fundamental regularities of the effect of electrolytic-plasma processing on the modification of steel surface layers.

strukturaviy bosqich davlat, EPO dan oldin va keyin 12X18N10T polatining mexanik xususiyatlari va korroziyaga chidamliligi.

"Research object is 12X18N10T steel, an austenitic grade structural steel.

Research methods. The electrolytic-plasma treatment (EPT) of the samples was carried out using an experimental setup developed by us. To study the state and properties of the samples before and after treatment, the following analytical methods were used: optical microscopy, scanning and transmission electron microscopy; X-ray diffraction analysis; determination of microhardness and wear resistance; and the distribution of carbon and nitrogen atoms in the modified layers was determined using optical emission spectrometry.

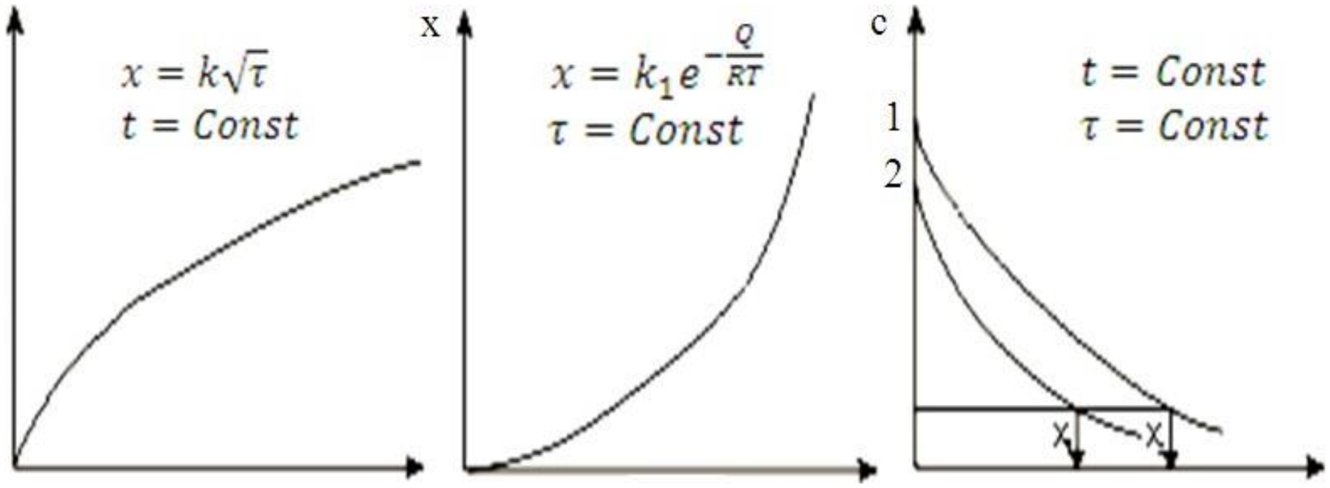
Scientific Originality In this work, for the first time, the phase composition, structure, mechanical properties, and corrosion resistance of modified surface layers of 12Kh18N10T steel treated under different electrolytic-plasma conditions are studied and characterized.

The established optimal regimes include electrolytic-plasma carburizing, nitrocarburizing, and nitriding of 12Kh18N10T steel samples. "New insights have been gained into the formation patterns of modified layer structures during the nitrocarburization of steel, as well as the phase composition of carbide and nitride layers depending on the electron-plasma processing (EPO) regime." "Carbide precipitates, carbonitride particles, and a well-developed dislocation substructure were identified in the modified surface layers of 12X18N10T steel, exerting a positive effect on its physical and mechanical properties.

"It is well established that the surface condition predominantly determines the strength and performance of machine components." "It is precisely the component surface that experiences intensified wear, bears elevated contact loads, and exhibits the highest susceptibility to corrosion." Surface hardening technologies are based on modifying the metal surface using energetic or physicochemical methods, which fundamentally alters its structure and properties. A promising approach to extending the service life of stainless steel components is thermochemical treatment-specifically carburizing, nitrocarburizing, and nitriding-which enhances their mechanical properties (microhardness, wear resistance) and corrosion resistance by forming modified surface layers.

Thermochemical treatment involves a combination of thermal and chemical processes designed to modify the composition, structure, and properties of a metal's surface layer. During the thermochemical treatment of steel, its surface becomes saturated with the respective alloying elements (N, Al , Cr , Si).

The resulting material layer on the component surface differs from the base metal in its chemical composition and is referred to as the diffusion layer. The total thickness of the diffusion layer is defined as the distance from the saturated surface to the core—the portion of the component unaffected by the active medium. The effective thickness of the diffusion layer is defined as the depth from the surface to the zone characterized by a specified maximum nominal value of the primary parameter. The primary parameter can be the concentration of the diffusing element, a performance property (e.g., hardness), or a structural characteristic. Crucial characteristics of the diffusion layer encompass its thickness, the phase composition, and the depth profile of the diffusing element concentration, along with specific material properties such as hardness, ductility, wear resistance, and corrosion resistance. In most cases, when layer growth is limited by elemental diffusion in the metal, the growth rate obeys a parabolic relationship 1.1 a): $y^2 = K\tau$, Here, y represents the diffusion layer thickness; K is the rate constant depending on the specific thermochemical treatment conditions; and τ is the saturation time. Constant K, which correlates with the diffusion coefficient of the element in the metal and consequently with the layer thickness, exhibits an exponential dependence on temperature (Figure 1.1). b): $K = K_0 \, \text{eksp}(Q/RT)$, Where Q is the effective activation energy, J/mol; and R represents the gas constant, equal to 8.31 J/(mol·K). Saturation with carbon or nitrogen, which form interstitial solid solutions with iron, results in faster diffusion compared to alloying with elements that form substitutional solid solutions, such as Cr, Al, Si, Mo, and others (see Figure). 1.1 c). Consequently, diffusion saturation with metals and silicon requires processing at elevated temperatures and for extended durations.



a) b) c)

Figure 1.1 – Diffusion layer thickness as a function of saturation duration (a), temperature (b), and concentration gradient across the diffusion layer thickness (c).

All other factors being equal, a higher concentration of the saturating element on the metal surface results in a greater thickness of the diffusion layer. Driven by the activity of the environment, this concentration determines the flux of elemental atoms to the surface, the rate of diffusion processes driving these atoms into the metal, the composition of the treated metal, and the resulting phase structure. Progression of the diffusion process leads to the formation of a diffusion zone in the surface layers of the treated metal, consisting of either a solid solution or chemical compounds. Determined by the 'metal-diffuser element' phase diagram, the nature of primary formations, the phase composition of the layer, and the concentration gradient across the diffusion layer thickness are strictly established. When a pure metal is saturated with various elements, the layer structure obeys a general rule, according to which diffusion between two components leads to the formation of corresponding single-phase zones from the Me–DE (diffuser element) phase equilibrium diagram intersected at the saturation temperature isotherm. Following the arrangement of single-phase regions on the phase diagram, the formation of diffusion layers occurs in a sequential manner.

In terms of kinetics, the penetration rate of the diffusing element into the metal depends directly on the concentration gradient dC/dx and the diffusion coefficient D. n the early stages of diffusion saturation, a significantly high dC/dx value drives a rapid increase in the overall thickness of the diffusion layer. Over time, the concentration gradient decreases, leading to a decline in the growth rate of the diffusion layer (Figure 1.1a).

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