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PHYSICO-CHEMICAL PROCESSES IN THE SURFACE LAYERS OF PARTS DURING PLASMA PROCESSING

ФІЗИКО-ХІМІЧНІ ПРОЦЕСИ В ПОВЕРХНЕВИХ ШАРАХ ДЕТАЛЕЙ ПІД ЧАС ПЛАЗМОВОЇ ОБРОБКИ

In the work, research is carried out on the surface layers of parts during plasma treatment, where various physico-chemical processes take place. The nature of their flow is determined by the temperature, rate and time of heating, the rate of cooling of the plasmatron, and the properties of the material that perceives plasma heating. Surface strengthening of metals is based on the ability of a plasma arc to generate high thermal current densities on a local area of the surface, which is sufficient to heat, melt or vaporize almost any metal. The main physical characteristic of plasma hardening is the temperature field, the value of which makes it possible to estimate the temperature in different zones of thermal influence, the rate of heating and cooling, and ultimately the structural and phase composition of the surface layer of cars.

Keywords*: strengthening, plasma treatment, laser treatment, plasmatron, microstructural analysis, combined method.*

Реальні умови експлуатації автомобільної техніки доводять про суттєвого збільшення навантажень, швидкісного і температурного режимів основних вузлів, механізмів і агрегатів з одночасним підвищенням надійності, довговічності і ресурсу автомобіля, що додає додаткові вимого зносостійкості для контактних поверхонь пар тертя в цілому.

До тридцяти відсотків зносу в контактуючих парах працюючих механізмів відводиться на процеси тертя. Тому процесам руйнувань поверхневого шару деталей і їх технологіям

зміцнення, приділяється особлива увага. Значну роль для комплексу сформованих зносостійких властивостей поверхневого шару відіграє відповідний спосіб обробки зміцнення, від якого в повній мірі залежить, довговічність, надійність, ресурс роботи механізмів і агрегатів автомобілів. Механізми утворення зносостійких структур наведені у багатьох працях провідних фахівців. В дослідницьких звітах надані режими обробок і кінцевий результат найбільш поширених технологічних методів обробки, де гарантовано при послідовному виконанні певних операцій отримуються відповідні мікроструктури з заданими показниками мікротвердості і зносостійкості на відповідних матеріалах. Суттєвим напрямом у технологіях зміцнення стало використання високоенергетичних джерел енергії, що дозволило розширити спектр модифікування поверхневих шарів, значно підвищити експлуатаційні і зносостійкі характеристики.

Ключові слова*: зміцнення,обробка плазмою, лазерна обробка, плазмотрон, мікроструктурний аналіз, комбіновані методи.*

Problem’s Formulation

During the operation of automotive equipment in modern conditions, additional factors arise that require a significant increase in loads, speed and temperature modes of operation of the main components, mechanisms and aggregates with a simultaneous increase in the reliability, durability and resource of the car. Up to 35% of the destruction of parts is attributed to friction processes in contacting pairs of units. Therefore, special attention is paid to the physical and mechanical properties of the surface layer of friction pair parts, and especially to strengthening technologies. The wear resistance of the surface layer and, as a result, the durability, reliability and service life of cars depends on the set of properties formed with certain strengthening technologies.

Analysis of the latest sources of research and publications

Over the past decades, in global practice, a significant number of technologies for strengthening the surface layer of parts have been introduced into machine-building production. High wear-resistant, physico-mechanical, operational properties of coatings, total costs for the technological process, equipment, consumables, environmental friendliness and safety are the main criteria for choosing strengthening methods in modern production. The mechanisms of formation of wear-resistant structures are given in many works of leading specialists [1—3].

Based on the analysis and research of modern methods of strengthening, a methodology for choosing the optimal option for using wear-resistant technologies has been developed and tested. the sequence of the combined method of modification of the surface layer by means of plasma treatment was studied. In the research reports, processing regimes and the final result of the most common technological processing methods are provided, where it is guaranteed that when certain operations are performed consistently, appropriate microstructures with specified indicators of microhardness and wear resistance are obtained on the corresponding materials.

The use of high-energy energy sources became a significant trend in strengthening technologies, which made it possible to expand the spectrum of modification of surface layers and significantly increase operational and wear-resistant characteristics [4—8]. The main methods of plasma surface strengthening of materials are shown in Fig. 1.

Formation of the study purpose

The purpose of the work is to investigate the effect of plasma heating on the mechanisms of formation of wear-resistant structures and their effect on the physical and mechanical characteristics of the surface of parts. Presentation of the main material Problem statement The real conditions of operation of automotive equipment prove a significant increase in loads, speed and temperature regimes of the main components, mechanisms and aggregates with a simultaneous increase in the reliability, durability and resource of the car, which adds additional requirements for wear resistance for the contact surfaces of the friction pairs as a whole. Up to thirty percent of wear in contacting pairs of working mechanisms is attributed to friction processes. Therefore, special attention is paid to the destruction processes of the surface layer of parts and their strengthening technologies. A significant role for the set of formed wear-resistant properties of the surface layer is played by the appropriate method of strengthening processing, which fully depends on the durability, reliability, resource of the mechanisms and units of cars.

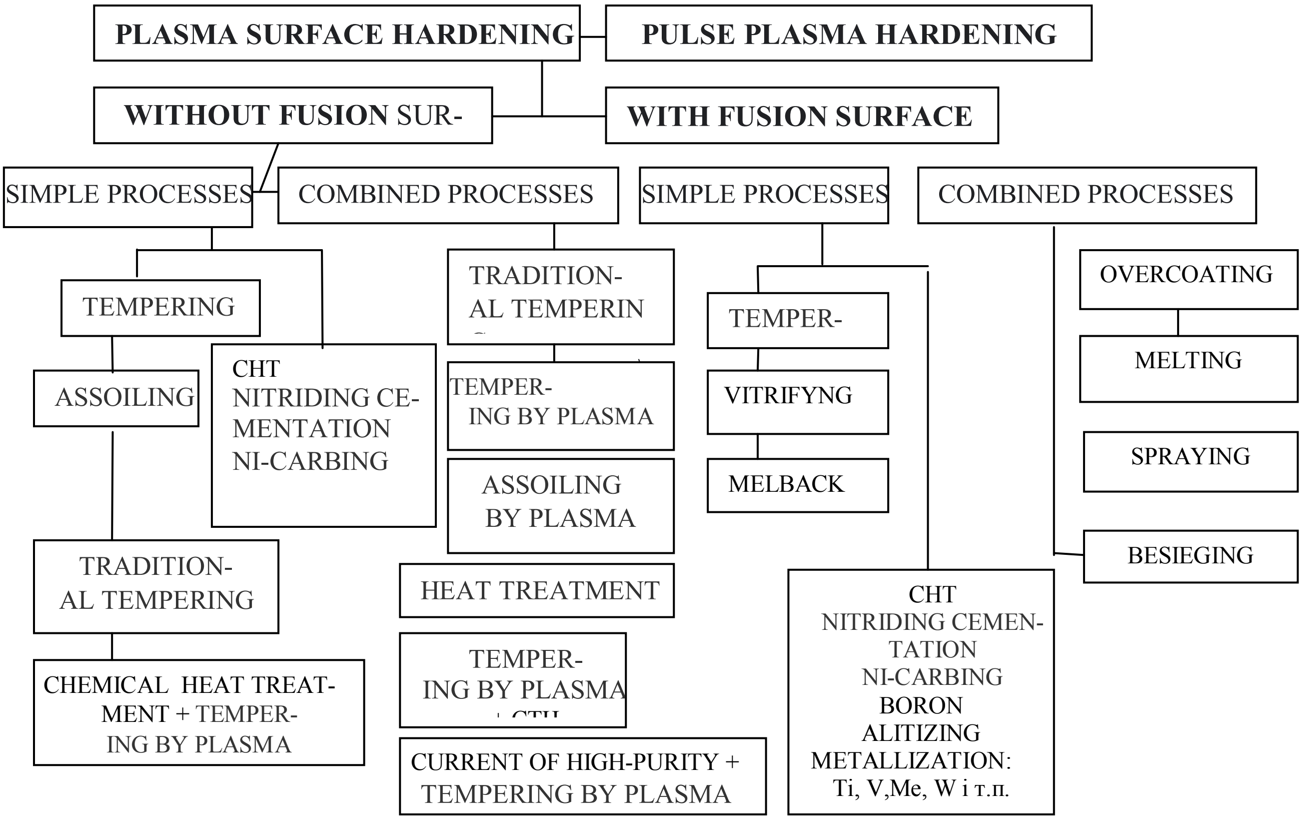

Fig. 1. Methods of plasma surface hardening of materials

Presenting main material

Surface hardening processes require the use of a concentrated source of heat with a heat flux density on the surface of the material of 103—106 W/cm^2. The main factor that distinguishes plasma heating from a laser heater is the mechanism of interaction between the energy source and the material. During laser heating, the global radiation flow directed at the surface of the material is partly reflected from it, and partly passes into the depth of the material. Radiation that penetrates deep into the material is almost completely absorbed by free electrons in the near-surface layer with a thickness of 0.1—1 μm [1]. Absorption leads to an increase in the energy of electrons, and as a result, to the intensification of their interaction with each other and the transfer of energy through the crystal lattice of the metal. The thermal state of the metal is characterized by two temperatures: electron T_e and lattice Ti, where T_e» Ti. With time (starting from the relaxation time t_P ~ 10—9s), the temperature difference Te-Ti becomes minimal and the thermal state of the material can be characterized by the total temperature T_m. The subsequent distribution of energy deep into the material is carried out by heat conduction. Heating of the surface of the material with plasma is carried out due to forced convective and radiant heat exchange

$$q = q_{k+}q_{л}.$$

For approximate calculations of heat fluxes on the surface, a model of radiative and convective heat exchange is used, which is based on the theory of the boundary layer [2—3].

The density of the convective heat flux is determined from the expression:

$$g_k = \sum \lambda \frac{dT}{dy} + \sum \rho v H + \rho \sum K_T\, v,$$

where λ — is the coefficient of thermal conductivity; H — is the enthalpy of a unit of mass; K_T — is the thermodiffusion coefficient; y — is a coordinate normal to the processing surface.

In general, convective heating of the surface is caused by the transfer of plasma energy under the action of heat conduction and diffusion. In practice, a simpler expression is used:

$$g = \alpha\left(T_{plaz} - T_{pov}\right),$$

where α is the coefficient of heat conduction; T_{plaz} — is the plasma temperature at the outer boundary of the boundary layer; T_{pov} — is the surface temperature.

The relationship between α and plasma parameters is determined through criterion dependences (Nusselt, Prandl, Reynolds number, etc.) selection for different cases of plasma interaction with the surface. The share of radiant energy transfer from the plasma to the metal surface is 2—8 % of the total energy balance. In cases of using pulsed plasma, the share of radiant heat exchange increases to 20—30 %. The radiant flux per unit of surface area in the normal direction is determined as

$$g_p = \xi_1 \xi_2 * \sigma_c T,$$

where ξ_1 — is the integral absorptive capacity of the surface; ξ_2 — is the degree of blackness of the plasma; σ_c —is the Stefan-Boltzmann constant; T — is the plasma temperature.

Given that the heat exchange between the energy flow and the surface is mainly determined by the convective component of the heat flow, turning off the radiant heat exchange (with the exception of the pulsed plasma) it is possible to calculate the heat flow according to the Fey-Riddel expression [5]

$$g = 0{,}763 P_g^{-0{,}6} \sqrt{\mu\rho} \left(\frac{du_r}{dr}\right)_0 \left(\frac{\rho_0\,\mu_0}{\rho\mu}\right)^{0{,}1} * \left[1 + \left(L_e^n - 1\right)\frac{\alpha\Delta h_p}{h}\right]\left(h - c_\rho^0 T_n\right);$$

or

$$g = 0{,}76 P_r^{-0{,}6} (\rho\mu)_\omega^{0{,}1} \rho\mu_s^{0{,}4}\left[1 + \left(L_e^{0{,}52} - 1\right)\right] * \frac{h_d}{h_s}\sqrt{\frac{dv_c}{dr}}\left(h_s - h_\omega\right),$$

where P_g — is the average Prandl number; $(\rho\mu)\omega$, $(\rho\mu)s$ — are the density and dynamic viscosity coefficient of the plasma at temperatures relative to the surface of the body and the outer boundary of the boundary layer; L_e — is the Lhos-Semenov number; L_d — is the dissociation energy multiplied by the weight the fate of atoms corresponding to the temperature of the current; dv/dr — is the velocity gradient at the critical point, which is equal; $t_o \sim U$ plasma / d nozzle; h_s — the total enthalpy of the plasma current.

When heating the metal surface with plasma (direct action plasmatron), the heating efficiency increases due to the electronic current q_e

$$q = q_k + q_{\text{л}} + q_e.$$

The effective efficiency of plasma-arc welding is 10—30% higher than when using a plasma jet and can reach 70=85% [3,6]. The energy balance of plasma heating at atmospheric pressure is as follows: 70% — convective heat exchange; 20% — electronic current; 10% — radiant heat exchange. When using plasma as a source of thermal energy, the distribution of the heat flow behind the heater spot is of greatest interest. The distribution of constant heat flux q_2 in the heating spot is approximately determined by the law of Gaussian normal distribution [7].

$$q_z = q^2 m \, exp\,(-Kr^2),$$

where K — is the accumulation coefficient characterizing the shape of the normal distribution curve and, as a result, the energy concentration in the heating spot; $q^2 m$ — maximum heat flow.

The equation of the heat distribution process in a massive body from a powerful fast-moving normally-distributed heat source, which is a plasma, has the form [7, 8]

$$T(\gamma, z, t) = T_0 + \frac{g}{2\pi\lambda\upsilon}\frac{exp\left(-\frac{z^2}{4\alpha t}\right)}{\sqrt{t(t_0+t)}},$$

where T — is the heating temperature; y, z — the width and depth of the heating spot; t — time; that is body temperature; g — effective power of the plasma current; λ, α — coefficients of thermal conductivity, thermal conductivity; υ — speed of movement of sources.

Comparative tests of steel samples 45, 40X for wear resistance with various hardening methods showed that plasma hardening is not inferior to electron beam and laser hardening (fig. 2).

Conducted studies have shown that the minimum depth of the hardened layer of metal that works satisfactorily under shock-abrasive wear is 2 mm. A decrease in the depth of the hardened metal layer causes intensive wear and discoloration: during shock-abrasive wear. The increase in resistance against shock-abrasive wear in the case of the application of complex technologies is due to the structure of the hardened layer, which combines high strength and viscosity. The cited research results show that plasma surface hardening is an effective method of increasing the wear resistance of parts of machines and tools experiencing various types of wear.

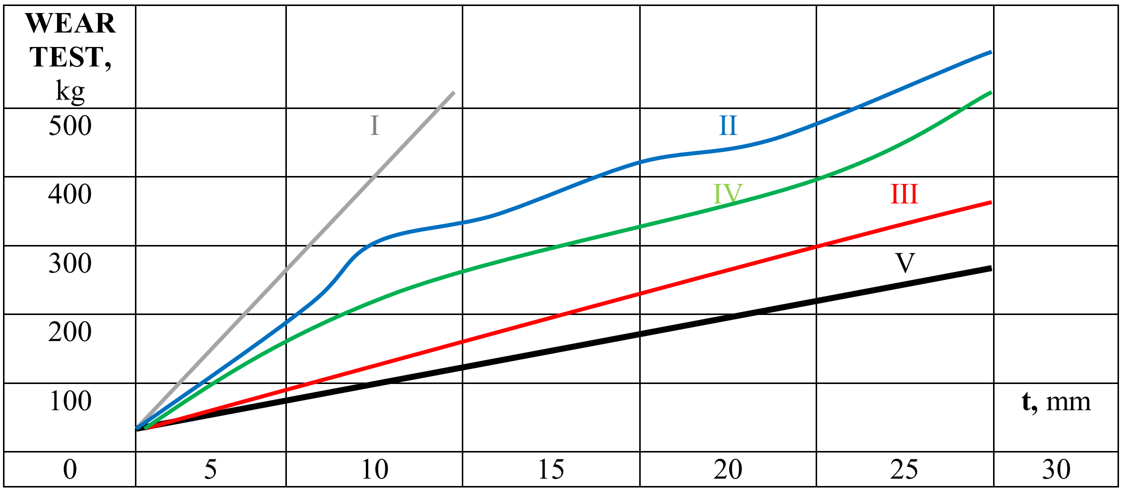

Fig. 2. The influence of the plasma alloying mode on the wear resistance of steel 45: 1— initial state; 2— volumetric CTT /nitrosementing; 3— plasma nitrocementation from the gas phase; 4— plasma nitrocementation from the solid phase; 5 — plasma nitrocementation from the solid phase + cold treatment

Conclusions

In the work, the issue of strengthening the surface layer of the part with plasma is considered, the main parameters and regimes of the plasma arc are calculated, which directly affects the quality and wear resistance of the surface, their physical, mechanical and durable characteristics. A graph of the wear resistance of the working surface depending on different methods of plasma treatment is constructed. Based on the analysis of the obtained results, the optimal and promising directions of processing were identified.

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