

ORIGINAL RESEARCH PAPER

## Hydrogen wear of metal friction elements of vehicle brakes for urban infrastructure facilities

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### ABSTRACT

**BACKGROUND AND OBJECTIVES:** In urban conditions, traffic flows are equipped with various types of braking devices operating in an aperiodic cyclic braking mode with a high surface-volume temperature of their friction pairs. Theoretical and experimental studies of hydrogen wear of movable and stationary joints at variable electrical surface-volume temperatures and equivalent stresses caused by pulsed specific loads, contributing to the emergence of gradients, made it possible to establish the following: positive and negative values of the heat of transfer correspond to forces directed, towards more cold or warmer parts of the product. Hydrogen moves in the metal friction element to its more heated section. Due to the mutual mass transfer of materials of friction pairs, the sign of their polarity changes, and negatively charged external hydrogen enhances the negative electronic field of the metal friction element, and as a result, leads to intensive wear of pairs of friction elements of the brakes. The purpose of the article is to assess the electron-ion interaction during hydrogen wear on the working surfaces of metal friction elements of friction pairs of brake devices.

**METHODS:** The data was obtained on a model disc, drum, and band-shoe brake and processed using a computer program package. As a result, graphical dependences of the main parameters of the brakes on the duration of hydrogenation were obtained.

**FINDINGS:** The research results have shown that the described main stages of hydrogen wear and destruction of a metal friction element during electrothermal-mechanical friction, as well as the influence of dislocation and double electrical layers in brake friction pairs, will be able to justify the choice of ways and methods to suppress hydrogenation and prevent the destruction of surfaces and, as a result, reduce hydrogen wear by 15% and improve the performance parameters of brake pairs by 10%.

**CONCLUSION:** This study examined the factors affecting the wear of metal brake friction elements of urban infrastructure vehicles. Empirical results have shown that positive and negative heat transfer values correspond to forces directed, towards colder or warmer parts of the product. These results can provide important information to factory designers for more efficient development of friction pairs of friction units, and researchers for further research and improvement of brake performance.

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## INTRODUCTION

One of the intense types of hydrogen wear of the rubbing surfaces of parts is accompanied by the destruction of the harder surface layer of a steel or cast-iron part and the transfer of wear products to a softer mating surface. The main factor influencing the hydrogen wear of metal friction elements of brakes of urban infrastructure vehicles is the dynamic coefficient of mutual overlap of their friction pairs. In drum and shoe brakes it reaches 0.7 - 0.75, and in disc and shoe brakes it is 0.15 - 0.25. Disc-pad brakes are made with one solid disc or two self-ventilated discs, between which cooling elements are located. The friction pairs of the braking devices were FK-24 materials – steel 35KHNL. Most friction pairs of brake devices operate in a hydrogen-containing environment, which, when contacted with their heated surfaces, contributes to the formation of hydrogen (Babenko, 2019; 2020). The interaction of released hydrogen with the surface layer of brake discs, drums, and pulleys causes embrittlement of their materials and, as a result, intense wear (Hrabovskiy et al., 2020). The mechanism of hydrogen wear by destruction during dislocation and double electrical layers in brake friction pairs is not clear enough, which makes it difficult to make a reasonable choice of ways and methods to suppress hydrogenation and prevent the destruction of surfaces. An analysis and synthesis of thermoelectric processes characterizing the electro-thermomechanical friction interactions of friction pairs of braking devices is given (Gontareva et al., 2020). The top layer of the polymer lining is isolated at temperatures higher than permissible for its material when the cracking process begins (Dzhanakhmedov et al., 2020). Thermokinetic models of the interaction of a metal friction element during its operation in various media are considered. The influence of surface and volume temperatures, specific loads, the coefficient of mutual overlap of friction pairs, the relationship between the number of reagents, the presence of inert gases, and the type of reactions on the rate of chemical reactions during the cracking process in the upper layer of polymer linings of friction units of brake devices has been established. It is shown that when assessing the equilibrium of a chemical reaction, it is necessary to take into account the change in the Gibbs energy (Ramkumar et al., 2024). It was noted that there is an intense release of hydrogen during electrothermomechanical friction

as a result of tribodestruction of water-containing polymer linings in brake friction pairs, creating a source of continuous supply of hydrogen into the surface layer of steel or cast-iron metal friction elements (Dzhanakhmedov et al., 2020). It has been established that under severe conditions of frictional interaction of the friction pairs of the band-shoe brake of a drill drawworks, the maximum surface-volume temperature is formed at a certain depth of the pulley rim (Kindrachuk et al., 2017, Kindrachuk et al., 2023). This creates conditions under which hydrogen, if it is adsorbed on the surface of the part, under the influence of a temperature gradient, diffuses deep into the surface, concentrates there, and increases wear (Liu et al., 2004, Zhang et al., 2019). The energy conditions for the occurrence of hydrogenation of the surface layer of metal friction elements were not taken into account (Duryagina, 2009). The influence of hydrogen on various properties of metals and alloys and the occurrence of specific defects in them is illustrated. Information about hydrogen brittleness and the influence of hydrogen on mechanical characteristics in the hydrogen-metal pair in groups of D. Mendeleev's periodic table has been expanded (Dzhanakhmedov et al., 2021). The work is devoted to the wear of sub-roughness of friction surfaces in a hydrogen-containing environment. In the latter, hydrogen pumped into the subsurface layer of a metal body interacts with its crystal lattice (Dzhanakhmedov et al., 2021). It is noted that the driving forces in hydrogen wear processes are temperature, pressure, deformation, structure, and crystal lattice defects (Kindrachuk et al., 2021, Kindrachuk et al., 2019, Kindrachuk et al., 2018). Physical and mechanical processes on the friction surface of hydrogen wear of machine parts and equipment were studied. The reasons for the release of hydrogen, hydrogenation of rubbing surfaces, and their destruction have been established (Volchenko et al., 2021). A complex picture of the behavior of hydrogen in surface layers during friction under the influence of various factors is shown, and the influence of "biographical" hydrogen on the wear of parts is determined. The reasons for the transfer of a harder material to a soft material during friction are outlined: steel to bronze, cast iron to plastic. Practical recommendations are given for suppressing hydrogen wear and increasing the durability and reliability of friction units of machines and equipment (Volchenko et al., 2020). At the same

time, the following was not considered: the effect of external hydrogen on the surface layer of the metal friction element and its entry into the subsurface layer by injection; the phenomenon of adhesion and the types of contacts of friction pairs during their frictional interaction were not taken into account, as well as the combination of adsorption - diffusion phenomena observed in the surface and subsurface layers of friction pairs (Fidrovskaya *et al.*, 2021, Kamarposhti *et al.*, 2024). And the most important thing is that there was no approach to external and internal hydrogen and their role in tribological reactions. It was established that under severe friction conditions, the maximum temperature is formed at a certain depth from the friction surfaces (Kindrachuk *et al.*, 2019, Fidrovskaya *et al.*, 2021). This creates conditions under which hydrogen if it is adsorbed on the surface of the part, under the influence of a temperature gradient, diffuses deep into the surface, concentrates there, causes embrittlement of the surface layers and increases wear. It was not specified what happens in the subsurface layer of the metal element with the structures of its crystal lattices (Volchenko *et al.*, 2019). It was noted that dislocations, vacancies, and grain boundaries have different binding energies and the binding energy of hydrogen affects the type of defect into which hydrogen is directed. At concentrations of 100 ppm and above, hydrogen begins to affect the electrical, chemical, and magnetic properties of materials (Buketov *et al.*, 2023). The purpose of the work is to evaluate the electron-ion interaction during hydrogen wear of the working surfaces of metal friction elements of friction pairs of brake devices. The latest research was carried out at a bench in laboratory conditions in Ivano-Frankivsk city, Ukraine in 2022. The scientific hypothesis is to establish a relationship between the operational parameters of brake friction pairs and the variable state of materials in their surface and subsurface layers.

## **MATERIALS AND METHODS**

### *The essence of hydrogen wear of metal friction elements of brake devices*

Hydrogen wear occurs as a result of cooperative (synergistic) interaction of surface phenomena and effects, exo-emission. Adsorption and tribodestruction of the surface layers of polymer pads, lead to the release of hydrogen. Together

with nonequilibrium processes occurring during the deformation of the surface layer of the metal, alternating electrical and thermal gradients are created in magnetic and equivalent voltage fields. This leads to the diffusion of hydrogen into the metal, its concentration in the subsurface layer, and accelerated wear or destruction of this layer. On the surface, during friction, isoelectronic emission occurs, supplying electrons that can solvate on water molecules and decompose them into oxygen and hydrogen. Hydrogen may be released as a result of secondary reactions of tribodestruction of hydrocarbons (for example, polymer pads). Inside the surface layer, a pumping system (in the form of micro bellows) of hydrogen takes place to a super-equilibrium concentration under the influence of the mentioned gradients that arise during deformation. The massive formation of defects in the deformed layer also increases the concentration of hydrogen, its destruction of the metal (fretting). The stages of hydrogen wear are given in [Table 1](#).

Depending on the nature of the external influence, one or another relationship arises between the two forms of the state of hydrogen:

- in the first case of corrosion (fretting corrosion), a gradual, irreversible transition of hydrogen dissolved in an equilibrium concentration into a segregated (molecular) form occurs;

- in the second case, when a mechanical effect occurs on the structure, hydrogen, under the influence of a gradient of equivalent stresses, is concentrated in the zone of its maximum values, where it transforms into a molecular form and causes destruction;

- in the third case, when there is friction and gradients of surface-volume temperatures, equivalent stresses, electric and magnetic fields appear on the surface, a super-equilibrium concentration of hydrogen is formed in the surface layer, released (during friction) from the adsorbed water of the plastic. The transition from a super-equilibrium concentration in a dissolved state under deformation conditions to a molecular form can occur almost instantly due to the dynamics of defect formation (Dzhanakhmedov *et al.*, 2014).

The hydrogen atom is magnetic, and the proton is electrically charged, which determines the connection between electrical phenomena during friction and the accumulation and migration of hydrogen under the influence of electric and magnetic fields.

Table 1: Stages of hydrogen wear in brake friction pairs

Stages	Processes in the contact zone during hydrogen wear	Reasons causing the process
1	Intensive release of hydrogen in the friction zone from moisture and non-metallic material of the rubbing pair.	Friction caused a tribochemical reaction
2	Desorption of moisture from the surface of a metal part.	Friction increases the surface temperature
3	Adsorption of hydrogen by the surface of a metal friction element.	Friction created the conditions for adsorption
4	Formation of double electrical layers in friction pairs.	To create an electric current gradient
5	Diffusion of hydrogen into the surface layers of metal elements of a rubbing pair, the speed of which is determined by temperature and stress gradients.	The friction created gradients of surface-volume temperature and equivalent stresses
6	Hydrogen concentration at a certain depth from the friction surface in the maximum temperature zone.	The friction created a temperature gradient below the surface
7	a) Low-temperature brittle destruction of the surface layer of metal elements of rubbing pairs, saturated with hydrogen, as a result of the formation of a large number of cracks with different energy levels in the contact zone.  b) High-temperature vicious destruction of the rubbing metal in the form of spreading onto the counter body as a result of liquefaction of the surface layer.	Mobilization of hydrogen from friction  Supersaturation of steel with hydrogen at heating temperature fluctuations of the order of 800...1000°C

Table 2: The chemical composition of materials steel 35HNL

Chemical element	Percentage content, %
Silicon (Si)	0,20 - 0,42
Copper (Cu), not more	0,30
Manganese (Mn)	0,40 - 0,90
Nickel (Ni)	0,70 - 0,90
Phosphorus (P), not more	0,047
Chrome (Cr)	0,50 - 0,80
Sulfur (S), not more	0,04

Transfer processes are caused by forces acting on the implanted hydrogen atoms. The force of electrical transfer occurs in the presence of electric current and is phenomenologically determined by the effective charge  $Z'$ , which is determined by Eq. 1 (Kindrachuk *et al.*, 2023):

$$F = -e Z' \text{grad} \Phi, \quad (1)$$

where  $e$  - elementary, positive charge;  $\text{grad} \Phi$  - applied electric field causing electric current.

The value  $e Z'$  characterizes the electric charge, which, in the presence of an external field, would be subject to the same forces as a hydrogen atom embedded in the metal. According to this definition, a positive or negative effective charge indicates that the effective force, which is determined by Eq. 2, is directed toward the cathode or anode. Analogue of electric transport. the heat transfer force occurs

in the presence of a surface-volume temperature gradient - degrees T; it is determined by the transfer heat  $Q'$  (Volchenko *et al.*, 2023):

$$F = Q' \text{grad} T / T. \quad (2)$$

Positive and negative values of heat transfer correspond to forces directed, towards colder or warmer parts of the product. Hydrogen moves in the metal friction element to its more heated section. The chemical composition of the material steel 35 KhNL is given in Table 2.

This is the basis for the process of dehydration of products, for example, chrome-plated aircraft power bolts. They are heated in a thermal oven to temperatures of 200°C, and sometimes to higher temperatures - 350...400°C and held for 20 minutes. In the case of simultaneous action of the electric field of the surface-volume temperature gradient on

Table 3: Chemical composition of lining materials

Friction pad	Content of elements, %								
	C <sub>free</sub>	S	Al	Cu	Fe	Si	Zn	Pb	Ni
G	16,40	3,70	3,33	7,66	3,69	0,64	2,78	3,10	0,260
B	24,20	2,95	3,95	3,34	14,90	1,08	2,23	0,08	0,020
C	18,10	-	0,84	11,80	27,40	-	3,28	0,13	-
A	22,70	-	1,97	5,84	14,30	1,12	3,67	0,16	0,023
H	19,60	-	0,24	5,13	19,50	0,34	1,10	0,01	0,004
D	19,10	-	0,13	11,77	35,20	0,29	3,52	0,05	0,008
J	22,30	-	0,31	0,23	30,90	0,21	0,07	2,08	0,001
K	-	-	0,50	9,50	32,70	0,28	2,68	2,40	-
L	-	-	0,36	10,50	34,00	0,29	2,97	2,66	-
E	19,4	19,4	0,67	8,23	19,4	0,11	2,41	0,09	0,01
F	19,0	19,0	0,82	9,85	19,6	0,24	3,56	0,16	0,05

Friction pad	Content of elements, %								
	Ti	Sb	Ba	Ca	K	Mn	Mg	Na	Sr
G	-	-	-	-	-	-	-	-	-
B	-	-	-	-	-	-	-	-	-
C	0,140	-	-	-	-	-	-	-	-
A	0,140	-	-	-	-	-	-	-	-
H	0,060	-	-	-	-	-	-	-	-
D	0,020	-	-	-	-	-	-	-	-
J	0,060	-	-	-	-	-	-	-	-
K	0,040	4,50	0,84	-	-	-	-	-	-
L	0,040	4,90	0,58	-	-	-	-	-	-
E	0,002	-	2,88	2,88	0,04	0,13	0,10	0,05	0,02
F	0,080	-	2,87	0,36	0,21	0,17	0,30	0,05	0,03

hydrogen atoms, a linear superposition of forces takes place. It follows that electrical, thermal, magnetic, and vibration phenomena during friction affect the wear of the surface layer as forces that control the movement and concentration of hydrogen. The opposite direction of electrical transfer and heat transfer will reduce wear, while the joint action in one direction will increase it on the hydrodonor and hydroacceptor subsystems. Hydrodonor consists of providing exoelectrons to water or hydrocarbon molecules adsorbed on the surface which, when decomposing, release hydrogen. The hydro acceptor subsystem consists of the absorption of released hydrogen by the surface layer as a result of the emergence in this layer of an internal source of heat and electrical potential during its deformation (Kindrachuk *et al.*, 2023). The chemical composition of lining materials is given in Table 3.

To heat and electricity, equivalent stresses arise in this zone, and an increase in the number of defects that can serve as microbellows for hydrogen occurs, which causes irreversibility and creates a super-non-equilibrium concentration. Depending on some reasons, for example, on the nature of loading, tribodestruction, and adsorption of certain or other substances, the design of the friction unit, and the degree of hydrogenation can vary significantly. Following this degree, there will be a transition from delayed destruction of the surface layer to brittle instantaneous destruction. The area of manifestation of hydrogen wear is extensive. Almost all rubbing surfaces of steel and cast-iron parts contain an increased amount of hydrogen and have increased wear. The presence of water vapor in the air creates favorable conditions for hydrogen wear, not to mention decomposition in the contact zone of the

friction material of the lining.

*Dislocations and double electrical layers in friction pairs of braking devices*

In real ionic crystals, potential charge carriers can be any irregularities, such as edges, steps on the surface, or intersections of dislocations. Charged dislocations are considered a significant reason for the appearance of charges during plastic deformation even without any contact with tribological interfaces during electrothermomechanical friction. During plastic deformation with increasing dislocation density, some dislocations are squeezed out of the slip plane. Dislocations of opposite signs annihilate (destroy) when they meet. The dislocation density decreases. At the same time, microcracks form, which destroy the crystal, which determines the amount of plastic deformation. During the operation of the part, periodic repeated processes of formation and destruction of this layer occur. Edge dislocations in metals with a lattice type formed during plastic deformation have a Burgers vector  $\alpha_0/2$  (Volchenko et al., 2023; Kindrachuk et al., 2023). Sliding occurs along the plane (Fig. 1 (a,b)). Fig. 1(a) shows a dislocation line in the crystal that limits the plane. Hydrogen ions of different signs alternate on an ideal dislocation line so that no excess charge exists. If there are kinks on the dislocation line, like this shown in Fig. 1(b),

then excess charges appear, positive or negative. If the dislocation as a whole must be charged, then there must be kinks on the dislocation line with ions predominantly of one sign. This is the case when the energies of the formation of cationic and anionic dislocations are different. Dislocations collect vacancies on their way through the crystal and carry them to the surface. The nature and concentration of impurities in the crystal, as well as their local distribution, are very important for the formation of charged regions. The formation of positively and negatively charged regions on the surface of a crack can be associated with an irregular distribution of impurities in the crystal due to the conditions of its growth.

One should take into account the possibility of local accumulation of charges due to their mechanical separation and the formation of an electrical double layer with an electrothermodynamic potential. The presence of anion and cation vacancies migrating from the surface into the crystal leads to the formation of a dipole layer near the surface and near screw dislocations due to differences in the formation energy and exchange energy. As for the magnetic field lines near the circular current (Fig. 2(a)) and the magnetic dipole (Fig. 2(b)), the fields are the same at large distances. In Fig. 3 shows the power of thermal saturation of the metal surface layer with hydrogen at

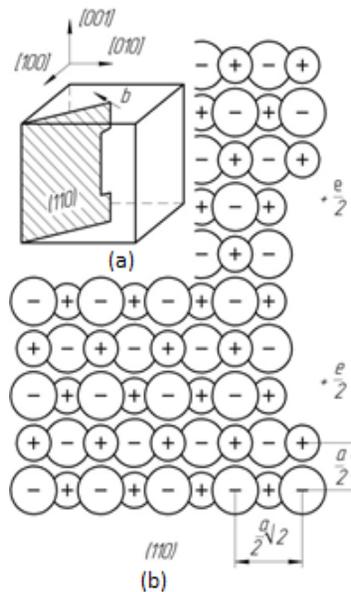


Fig. 1(a,b): Geometry of a charged edge dislocation: lattice constant (a); elementary charge (b)

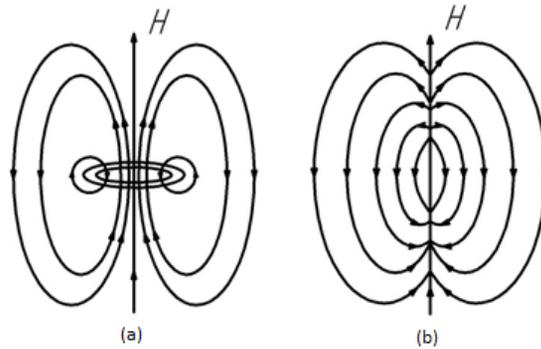


Fig. 2(a,b): Magnetic field lines near a circular current (a) and a magnetic dipole (b)

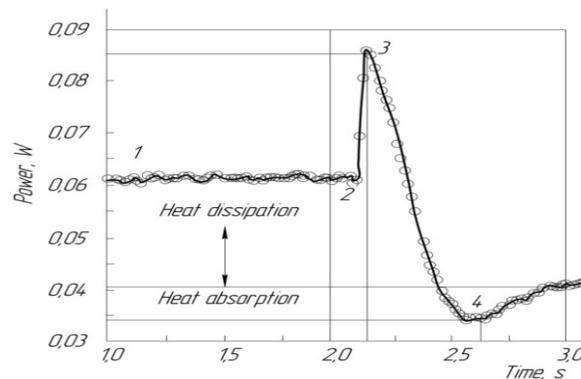


Fig. 3: Regularity of thermal saturation of the surface metal layer with hydrogen at  $p = 1,2$  MPa

$p = 1,2$  MPa versus time.

Straight line 1-2 for a time of 2.1 s characterizes the power equilibrium of the surface layer at  $P = 0,061$  W. The micro-explosion lasts 0.05 s with a power of 0.086 W. After which, throughout 0,5 s, the power dropped to 0,034 W. It should be emphasized that explosive processes can cover part of the film or be repeated if, after the first explosion, the formation of the film continues, which makes it difficult to carry out spontaneous explosive processes. The processes of formation and changes in the structure of condensates at high surface-volume temperatures, as well as the size of the particles involved in the process, are of decisive importance for specific chemical mechanisms forming films. Processes can be initiated by cracks after reaching the ultimate strength. In high-temperature reactions, physical and chemical processes are closely intertwined. It has been established that adsorption layers are

responsible for the formation of uncompensated charges, due to which polar molecules or charged particles accumulate on the surface, compensating the internal charges. The movement of charges may be due to differences in contact potentials that arise inside the oxide films and lead to high field strengths due to the small distances.

*Mechanical separation is achieved by lifting adhesive films from metal surfaces*

There is usually an excess positive charge on the fresh surface of a crack. In the temperature range of 110 – 425 K, the maximum charge density does not depend on the temperature of the crystal. The size of uniformly charged regions reaches several millimeters. There is no correlation between the accumulation of charges on the mirror-like surfaces of the crack. Based on the above, a structural diagram of double electrical layers has been drawn up, creating

an electrothermodynamic potential in the surface and near-surface layers with ionized hydrogen in friction pairs of a belt (a) and drum (b) shoe brake (Table 4). During hydrogen wear by dispersion, no scuffing, tearing, or noticeable transfer of material from one friction surface to another is observed on the friction surfaces. The friction surfaces may have shine and very small scratches, marks that are not visible to the naked eye and are directed in the direction of sliding. Atomic hydrogen, depending on its amount in the surface layer, enhances the dispersion of the metal. It has been established that with slight hydrogenation, the wear resistance of steel 45 samples increases slightly, and with further

hydrogenation, it decreases. This is explained by the fact that with slight hydrogenation the hardness of steel increases slightly.

Fig. 4 shows the dependence of the change in the relative microhardness of steel 45 on the duration of hydrogenation. As can be seen from the figure, the microhardness increases during the first two hours of hydrogenation, and then decreases and becomes less than the initial one at the sixth stage of testing. This indicates that when the steel surface is saturated with hydrogen, the layer loosens and, as a consequence, its wear resistance decreases. Fig. 5 shows the dependence of the amount of absorbed hydrogen and the wear rate on the duration of hydrogenation.

Table 4: Structural diagram of double electrical layers with ionized hydrogen in friction pairs of a belt (a) and drum (b) - shoe brake

Name of working elements of friction pairs and their charge	Hydrogen ionization			
	H <sup>-</sup>	H <sup>+</sup>	H <sup>±</sup>	
The working surface of the pad	+	-	+	+ -
The outer working surface of the metal layer	-	-	+	+ -
The inner working surface of the metal layer	-	-	+	+ -
The outer surface of the subsurface metal layer	-	-	+	+ -
The inner surface of the subsurface metal layer	-	-	+	+ -
The remaining volume of the body of the metal friction element with hydrogen	-	-	+	+ -

(a)

Name of working elements of friction pairs and their charge	Hydrogen ionization			
	H <sup>-</sup>	H <sup>+</sup>	H <sup>±</sup>	
The remaining volume of the body of the metal friction element with hydrogen	-	-	+	+ -
The outer surface of the subsurface metal layer	-	-	+	+ -
The inner surface of the subsurface metal layer	-	-	+	+ -
The outer working surface of the metal layer	-	-	+	+ -
The inner working surface of the metal layer	-	-	+	+ -
The working surface of the pad	+	-	+	+ -

(b)

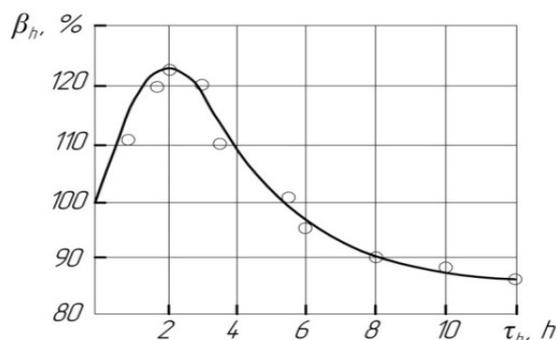


Fig. 4: Dependence of the relative microhardness of steel 45 on the duration of hydrogenation

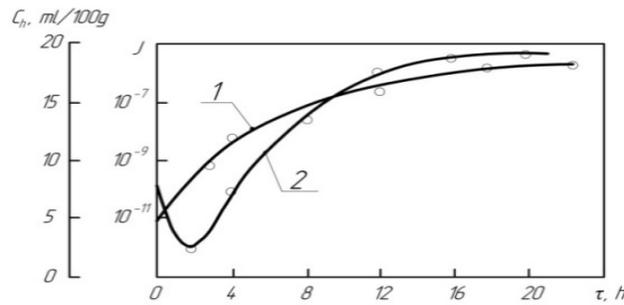


Fig.5: Dependence of the amount of absorbed hydrogen  $C_n$  (1) and wear rate  $J$  (2) on the duration of hydrogenation

Hydrogen wear by destruction is distinguished by the fact that the surface layer of metal (cast iron or steel) up to 1 - 2 microns thick under certain conditions is destroyed instantly. This happens when a sufficiently large amount of hydrogen accumulates in the surface layer. The accumulation of hydrogen is facilitated by the thermal destruction of the surface layer of the lining during friction since hydrogen can occupy a large number of adsorption centers on the surface. During friction, the concentration of hydrogen in steel continuously increases. Hydrogen penetrates the emerging microcracks of the cavity, intercrystalline boundaries, and other places. Under friction conditions, periodic plastic deformation of the surface layer occurs, and the volume of defective areas changes. Hydrogen entering the microcavities is hemolyzed and, unable to escape back when the volume decreases, tends to expand the microcavity, creating large specific loads.

## CONCLUSION

This study examined the factors affecting the wear of metal brake friction elements of urban infrastructure vehicles. As a result of theoretical and experimental studies of hydrogen wear of movable and stationary joints, which were carried out at variable electrical surface-volume temperatures and equivalent voltages and were caused by pulsed specific loads that contribute to the emergence of gradients, it was possible to establish the following. Empirical results have shown that positive and negative heat transfer values correspond to forces directed, towards colder or warmer parts of the product. This occurs because hydrogen moves in the metal friction element to its more heated section.

Also, due to the mutual mass transfer of materials in the friction pairs of brake devices, the sign of their polarity changes, and negatively charged external hydrogen enhances the negative electronic field of the metal friction element. Research has established that the hydrogen atom is magnetic, and the proton is electrically charged, and this determines the connection between electrical phenomena during friction and the accumulation and migration of hydrogen under the influence of magnetic and electric fields. Heat transfer processes are caused by forces acting on the embedded hydrogen atoms. The force of electrical transfer occurs in the presence of electric current and is phenomenologically determined by the effective charge, which is confirmed by empirical dependencies. Due to the lack of knowledge of the phenomena and effects, as well as the complexity of the processes during hydrogen wear of the working surfaces of the metal friction elements of brakes, the structure of their metal under the influence of hydrogen turns into a dynamically changing system, passing into a state of chaos (catastrophically intense wear and emergency destruction). Because of the above, it has been established that during electrothermomechanical friction, the working surface of the metal friction element is exposed to hydrogen, which, under the influence of a gradient of equivalent stresses, is concentrated in the zone of their maximum values, where it transforms into a molecular form and causes destruction, which negatively affects the operation of friction pairs of brake devices and as a result, on the operation of the vehicle as a whole. With further study of hydrogen wear, it is necessary to develop a set of methods to combat such a negative phenomenon.

### AUTHOR CONTRIBUTION

N. Fidrovskaya reviewed the literature and prepared the experiment. S. Dotsenko reviewed the literature, set up the experiment, and analyzed and interpreted the data. S. Nikipchuk and V. Nesterenko based on experimental data, using a computer program package, built the graphical dependencies presented in the article. M. Ostashuk and P. Yefimenko helped in the literature review and preparation of the manuscript.

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### CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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### ABBREVIATION

$\alpha_0/2$	Burgers vector
$\beta_H$	Relative microhardness
$C_H$	Amount of absorbed hydrogen
$J$	<i>Duration of hydrogenation</i>
$e$	Elementary, positive charge
grad T	Temperature gradient
grad $\phi$	Applied electric field causing electric current
$P$	Power
$\rho$	Specific loads
$Q'$	The heat of transfer
$\tau$	Time
$Z'$	Effective charge

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