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# TRIBOLOGICAL PROPERTIES OF HIGH NITROGEN STEELS AFTER HYDROGENATION

# Valerii Kolesnikov, Alexander Balitskii<sup>x</sup>, Jacek Eliasz<sup>xx</sup>

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Summary. The articles has presents the results and original experimentals data of wear resistance of high nitrogen steels after hydrogenation. The results of tribological tests revealed that the size of the wear products after hydrogenation are much higher, than before the hydrogenation of samples (linear sizes has differed in 5-6 times).

Key words: hydrogen resistance, high nitrogen steels, wear products.

### INTRODUCTION

The operational stability of the industrial equipment is determined by the intensity of deterioration of the interfaced surfaces, and up to 80 % of refusals of machines and mechanisms occur became of to fracture of materials in friction units [1, 2]. High nitrogen steels are the perspective materials as a hydrogen resistant materials, including in the friction conditions. The problem of hydrogen wear up to this time still is not complete investigated, but some data it is possible to find in the papers [1-8]. Hydrogen embrittlement is the process by which various metals (including highstrength steel) become brittle up to fracture due to exposition in hydrogen. The mechanism of this phenomenon based on the diffusion of hydrogen atoms through the metal. At high temperatures, the elevated solubility of hydrogen allows hydrogen to diffuse into the metal (or the hydrogen can diffuse in at a low temperature, assisted by a concentration gradient). When these hydrogen atoms re-combine in minuscule voids of the metal matrix to form hydrogen molecules, they create pressure from inside. This pressure can increase to levels where the metal has reduced ductility and tensile strength up to the cracks initiation (hydrogen induced cracking, or HIC). High-strength and lowalloy steels, nickel and titanium alloys are also susceptible to hydrogen [3]. The purpose of the work is to analysed literary sources devoted hydrogen resistant steels and investigated the wear products after hydrogenation.

# EXPERIMENTAL PROCEDURE

The wear resistance was measured on SMT-1(2070) friction machine according the roller-shoe scheme under the conditions of boundary and dry friction. As the counterbody, we used a roller made of steel 1.0503 (VSG) equivalent of 45 hardened steel with a hardness of 55...60 HRC and stainless steel (with Cr = 11...15 %).

Hydrogenation of alloys was carried out at a current from 50 to 100  $A/m^2$  in a solution of sulfuric acid (26% H<sub>2</sub>SO<sub>4</sub>).

The wear products were studied with a Neophot-2 microscope by treating the images of a Canon EOS 30D digital camera on a personal computer, and friction surfaces were examined with an EVO-40XVP electron microscope with an INCA Energy 350 system of X-ray microanalysis. The wear products of high-nitrogen austenitic steels and steel 45 were separated with a permanent magnet.

Num.	Grade	C	Cr	Mn	Si	Ni	V	Si	Mo	V	N
1.	Alloy No. 1 (DDT 68)	0.06	17.5	19.4	0.52	0.13	0.14	0.52	2.08	0.14	0.97

Table 1. Chemical	<b>Compositions of S</b>	Steels and Allo	ys (wt. %)
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#### **RESULTS AND DISCUSSIONS**

The surface layers of manganese steel and stainless steel are destroyed as a result of microcracking (fig.1) and separation of fragments of the material.



Fig. 1. Friction surfaces of stainless steel (counter-body (a roller)) under the normal friction conditions (a). EDX – spectra of fracture surfaces of stainless steel (b)

The appearance of wear products is quite diverse, which provides evidence of different characters of fracture of the investigated materials and, correspondingly, of their different wear rates. Subsequent experiments with these samples (with increasing of time after hydrogenation), the wear rate is reduced (probably due to the two factors: the changing the characteristics of samples and decreasig the amount of hydrogen in the surface layer of the alloy). It was established that if the loading increases, the sizes of the wear products has increased. For non hydrogenated samples there are 25...40  $\mu$ m (load 400 N), 25...100  $\mu$ m (load 500 N). For the hydrogenated samples size of particles

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Fig. 2. Wear of alloys under conditions of dry friction under a load P = 450 N ((1) (alloy No. 1 is steel 1,0503); (2) (alloy No. 1 is stainless steel) (immediately after hydrogenation)

The results of tribological tests revealed that the sizes of the wear products after hydrogenation are much higher than before the hydrogenation of samples (linear sizes increased in 5 - 6 times) [2].



Taking into account the general laws of fracture of alloys (and taking into account the average statistical sizes of wear products), applying the methods of mathematical statistics, we established in mathematical statistics, we established the general structural-energetic criteria describing the relation of fracture intensity with the parameters of structural-phase composition and the sizes of wear product with the parameters of structural-phase friction composition and the sizes of wear products with regard for the external friction

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atomic interaction between hydrogen and alloying elements in steel and the effect of alloying elements on hydrogen migration, hydrogen-induced phase transformations and mechanical properties of hydrogenated steels. It is shown that a reason for HE is the hydrogen-caused increase in the concentration of free electrons leading to a striking decrease of the shear module, which results in a strongly modified mechanism of plastic deformation leading to pseudo-brittle fracture.

deformation teacher is applicable for all non hydride-forming metals. The The developed concept is applicable for all non hydride-forming metals. The knowledge of optimal chemical compositions of hydrogen-resistant austenitic steels is obtained from the studies of Me-H bonding energies in the solid solution, mobility of dislocations, hydrogen migration enthalpy and hydrogen-induced phase transformations in relation to mechanical properties.



Fig. 4. Stress-strain curve of hydrogen-free and hydrogen-charged steels. Effect of Ni in a model steel (a); effect of chemical composition on hydrogen migration enthalpy and hydrogen embrittlement of austenitic steels (b) [10]

The tendency of hydrogen to localization should be considered as a major factor of hydrogen degradation. The localization of hydrogen allows significant changes in materials even at very low hydrogen concentrations. Effects arising at hydrogen concentrations in metals of the order of 0.1 - 0.01 at. % would not exist at all if its distribution were uniform [11]. Two effects different in nature are concerned with the factor of localization. The essence of the first one is that, in the already perfect crystalline lattice of metal, the presence of clusters [12, 13] in the form of a nearly periodic lattice of the protonic subsystem (electrons of hydrogen and the metal are collective), which is "dipped" into the lattice of the metal and has a lattice constant of order nearly identical to that of the metal [13], is more favorable in terms of energy rather than the uniform distribution of the dissolved hydrogen. This means that the atomic concentration of hydrogen in these regions of the phase enriched in hydrogen approaches 100%. This effect depends on the electron density of the metal and on temperature, since clusters become unstable and resolve at temperatures of about 500 K, i.e., when the effects of hydrogen embrittlement of metals disappear.

The other effect of hydrogen localization is its segregation in defects of the crystalline structure [14, 15, 16]. The importance of this effect for the behavior of materials is attributable to the fact that, on the one hand, it is structural defects, their structure, and properties that determine the properties of materials [11].

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# CONCLUSIONS

In the absence of hydrogenation, the sizes of wear products has range from 20 M. For hydrogenation 40 to 100  $\mu$ m under P = 500 N. For hydrogenation 20 m under a load p In the absence of hydrogenation, the sizes of under P = 500 N. For hydrogenation, the sizes of war products are above 350 µm under a load P = 200 N and from 20 µm under P = 400 N and from 40 to 100 µm under a load P = 200 m under P = 200 m under P = 400 N. The surface layers of mangan In the absence of N, and from 40 to 100 pm under a load P = 250 N. For hydrogeneration with the sizes of wear products are above 350 µm under a load P = 250 N and P = 240 µm under P = 400 f wear products are under a load P = 250 magnetic specimens, the sizes of wear products are under P = 400 N. The surface layers of manganese steel specimens, the sizes of under P = 400 N. The surface layers of manganese steel are from 600 to 1000 µm under P = 400 N. The surface layers of manganese steel are from 600 to 1000 µm under P = 400 N. The surface layers of manganese steel are from 600 to 1000 µm under P = 400 N. The surface layers of manganese steel are the steel are destroyed as a result of microcracking and separation of fractions are steel are destroyed as a result of microcracking and separation of fractions are steel are destroyed as a result of microcracking and separation of fractions are steel are destroyed as a result of microcracking and separation of fractions are steel are destroyed as a result of microcracking and separation of fractions are steel are destroyed as a result of microcracking and separation of fractions are steel are destroyed as a result of microcracking and separation of fractions are steel are destroyed as a result of microcracking and separation of fractions are steel are destroyed as a result of microcracking and separation of fractions are steel are destroyed as a result of microcracking are steel are destroyed as a result of microcracking are steel are steel are destroyed as a result of microcracking are steel are st specimens, the sizes of  $\mu m$  under P = 400 rm incrocracking and separation of  $\frac{250 \text{ M}}{\text{fragmas}}$ range from 600 to 1000  $\mu m$  under P = 400 rm incrocracking and separation of  $\frac{250 \text{ M}}{\text{fragmas}}$ stainless steel are destroyed as a result of microcracking and separation of  $\frac{1}{\text{fragmas}}$ 

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# ИССЛЕДОВАНИЕ ТРИБОТЕХНИЧЕСКИХ СВОЙСТВ ВЫСОКОАЗОТИСТЫХ СТАЛЕЙ ПОСЛЕ НАВОДОРАЖИВАНИЯ

# Валерий Колесников, Александр Балицкий, Яцек Елиаш

посвящена экспериментальным данным триботехнических свойств Аннотация. Статья Анвотация. высокоазотистых сталей после наводораживания. Результаты трибологических испытаний выявили, высоковзотно продукции одежды после наводораживания намного выше, чем до наводораживания то размер продукции одежды после наводораживания намного выше, чем до наводораживания ето размор промер на до наводораживания с памного выше, чем до наводораживания образцов (линейные размеры отличаются 5 - 6 разами). Также приведен краткий анализ литературных и интернет источников посвященных водородной стойки сталей.

Ключевые слова: водородстойкая сталь, высокоазотистая сталь, нержавеющая сталь, продукты HIHOCH.

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#### RESULTS AND DISCUSSIONS

The surface layers of manganese steel and stainless steel are destroyed as a result of microcracking (fig.1) and separation of fragments of the material.



Fig. 1. Friction surfaces of stainless steel (counter-body (a roller)) under the normal friction conditions (a). EDX - spectra of fracture surfaces of stainless steel (b)

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Fig. 4. Stress-strain curve of hydrogen-free and hydrogen-charged steels. Effect of Ni in a model steel (a); effect of chemical composition on hydrogen migration enthalpy and hydrogen embrittlement of austenitic steels (b) [10]

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# Валерий Колесников, Александр Балицкий, Яцек Елиаш

посвящена экспериментальным данным триботехнических свойств Аннотация. Статья Анвотация. высокоазотистых сталей после наводораживания. Результаты трибологических испытаний выявили, высоковзотно продукции одежды после наводораживания намного выше, чем до наводораживания то размер продукции одежды после наводораживания намного выше, чем до наводораживания ето размор промер на до наводораживания с памного выше, чем до наводораживания образцов (линейные размеры отличаются 5 - 6 разами). Также приведен краткий анализ литературных и интернет источников посвященных водородной стойки сталей.

Ключевые слова: водородстойкая сталь, высокоазотистая сталь, нержавеющая сталь, продукты HIHOCH.

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TRIBOLOGICAL PROPERTIES OF HIGH NITROGEN

### TRIBOLOGICAL PROPERTIES OF HIGH NITROGEN STEELS AFTER HYDROGENATION

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Summary. The articles has presents the results and original experimentals data of wear resistance of high nirogen steels after hydrogenation. The results of tribological tests revealed that the size of the wear product after hydrogenation are much higher, than before the hydrogenation of samples (linear sizes has differed in 5. 6 times).

Key words: hydrogen resistance, high nitrogen steels, wear products.

#### INTRODUCTION

The operational stability of the industrial equipment is determined by the intensity of deterioration of the interfaced surfaces, and up to 80 % of refusals of machines and mechanisms occur became of to fracture of materials in friction units 2]. High nitrogen steels are the perspective materials as a hydrogen resistant materials including in the friction conditions. The problem of hydrogen wear up to this time still is not complete investigated, but some data it is possible to find in the papers [1-4] Hydrogen embrittlement is the process by which various metals (including high strength steel) become brittle up to fracture due to exposition in hydrogen. It mechanism of this phenomenon based on the diffusion of hydrogen atoms through the metal. At high temperatures, the elevated solubility of hydrogen allows hydrogen to diffuse into the metal of diffuse into the metal (or the hydrogen can diffuse in at a low temperature, assisted by a concentration gradient use the hydrogen can diffuse in at a low temperature, assisted by a concentration gradient use the hydrogen can diffuse in at a low temperature. concentration gradient). When these hydrogen atoms re-combine in minuscule void of the metal matrix to 6 minuscule void of the the metal matrix to form hydrogen molecules, they create pressure from inside. This pressure can increase to hydrogen molecules, they create pressure from inside strength pressure can increase to levels where the metal has reduced ductility and tensile strength and let up to the cracks initiation (hydrogen induced cracking, or HIC). High-strength and low alloy steels, nickel and size alloy steels, nickel and titanium alloys are also susceptible to hydrogen [3]. The purpose of the work is to analyze the steels and titanium alloys are also susceptible to hydrogen [3]. of the work is to analysed literary sources devoted hydrogen [3]. Inter and investigated the wear production of the work of the stand steels and investigated the wear production of the stand steels and investigated the wear production of the standard steels and steels investigated the wear products after hydrogenation.

## EXPERIMENTAL PROCEDURE

The wear resistance was measured on SMT-1(2070) friction machine according the roller-shoe scheme under the conditions of boundary and dry friction. As the counterbody, we used a roller made of steel 1.0503 (VSG) equivalent of 45 hardened steel with a hardness of 55...60 HRC and stainless steel (with Cr = 11...15 %).

Hydrogenation of alloys was carried out at a current from 50 to 100  $A/m^2$  in a solution of sulfuric acid (26% H<sub>2</sub>SO<sub>4</sub>).

The wear products were studied with a Neophot-2 microscope by treating the images of a Canon EOS 30D digital camera on a personal computer, and friction surfaces were examined with an EVO-40XVP electron microscope with an INCA Energy 350 system of X-ray microanalysis. The wear products of high-nitrogen austenitic steels and steel 45 were separated with a permanent magnet.

### Table 1. Chemical Compositions of Steels and Alloys (wt. %)

Num.	Grade	C	Cr	Mn	Si	Ni	V	Si	Mo	W	N
1.	Alloy No. 1 (DDT 68)	0.06	17.5	19.4	0.52	0.13	0.14	0.52	2.08	0.14	0.97

#### **RESULTS AND DISCUSSIONS**

The surface layers of manganese steel and stainless steel are destroyed as a result of microcracking (fig.1) and separation of fragments of the material.



Fig. 1. Friction surfaces of stainless steel (counter-body (a roller)) under the normal friction conditions (a). EDX – spectra of fracture surfaces of stainless steel (b)

The appearance of wear products is quite diverse, which provides evidence of different characters of fracture of the investigated materials and, correspondingly, of their different wear rates. Subsequent experiments with these samples (with increasing of time after hydrogenation), the wear rate is reduced (probably due to the two factors: the changing the characteristics of samples and decreasig the amount of hydrogen in the surface layer of the alloy). It was established that if the loading increases, the sizes of the wear products has increased. For non hydrogenated samples there are 25...40  $\mu$ m (load 400 N), 25...100  $\mu$ m (load 500 N). For the hydrogenated samples size of particles

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are from 350 µm (with loadig 250 N) up to 600 microns (with loading 400 N). The morphology of the wear products has shown the significant difference in the intensity of appearance of wear particles of hydrogenated and not hydrogenated alloys.



Fig. 2. Wear of alloys under conditions of dry friction under a load  $P = 450 \text{ N} ((1) \text{ (alloy No. 1 is steel 1,0503); (2) (alloy No. 1 is stainless steel) (immediately after hydrogenatic)$ 

The results of tribological tests revealed that the sizes of the wear products after hydrogenation are much higher than before the hydrogenation of samples (linear sizes increased in 5 - 6 times) [2].



Fig. 3. Wear products: a) before hydrogenation; b) after hydrogenation

Taking into account the general laws of fracture of alloys (and taking in account the average statistical sizes of wear products), applying the methods of mathematical statistics, we established the general structural-energetic oriten describing the relation of fracture intensity with the parameters of structural-phase parameters (slip velocity and local) (4.1)

The problem of hydrogen resistance of steels is complicated, some data it's engineering materials for long term service in hydrogenating environments. The approach is based on the electronic concept of hydrogen embrittlement (HE), studies of

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atomic interaction between hydrogen and alloying elements in steel and the effect of alloying elements on hydrogen migration, hydrogen-induced phase transformations and mechanical properties of hydrogenated steels. It is shown that a reason for HE is the hydrogen-caused increase in the concentration of free electrons leading to a striking decrease of the shear module, which results in a strongly modified mechanism of plastic deformation leading to pseudo-brittle fracture.

The developed concept is applicable for all non hydride-forming metals. The knowledge of optimal chemical compositions of hydrogen-resistant austenitic steels is obtained from the studies of Me-H bonding energies in the solid solution, mobility of dislocations, hydrogen migration enthalpy and hydrogen-induced phase transformations in relation to mechanical properties.



Fig. 4. Stress-strain curve of hydrogen-free and hydrogen-charged steels. Effect of Ni in a model steel (a); effect of chemical composition on hydrogen migration enthalpy and hydrogen embrittlement of austenitic steels (b) [10]

The tendency of hydrogen to localization should be considered as a major factor of hydrogen degradation. The localization of hydrogen allows significant changes in materials even at very low hydrogen concentrations. Effects arising at hydrogen concentrations in metals of the order of 0.1 - 0.01 at. % would not exist at all if its distribution were uniform [11]. Two effects different in nature are concerned with the factor of localization. The essence of the first one is that, in the already perfect crystalline lattice of metal, the presence of clusters [12, 13] in the form of a nearly periodic lattice of the protonic subsystem (electrons of hydrogen and the metal are collective), which is "dipped" into the lattice of the metal and has a lattice constant of order nearly identical to that of the metal [13], is more favorable in terms of energy rather than the uniform distribution of the dissolved hydrogen. This means that the atomic concentration of hydrogen in these regions of the phase enriched in hydrogen approaches 100%. This effect depends on the electron density of the metal and on temperature, since clusters become unstable and resolve at temperatures of about 500 K, i.e., when the effects of hydrogen embrittlement of metals disappear.

The other effect of hydrogen localization is its segregation in defects of the crystalline structure [14, 15, 16]. The importance of this effect for the behavior of materials is attributable to the fact that, on the one hand, it is structural defects, their structure, and properties that determine the properties of materials [11].

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### CONCLUSIONS

In the absence of hydrogenation, the sizes of wear products has range from 25 has no N and from 40 to 100 µm under P = 500 N. For hydrogenation In the absence of hydrogenation, and to 100  $\mu$ m under P = 500 N. For hydrogenated 40  $\mu$ m under P = 400 N and from 40 to 100  $\mu$ m under a load P = 200in the dec P = 400 N and from 40 km are above 350  $\mu$ m under a load P = 250 N and 40  $\mu$ m under P = 400 N. The surface layers of manganeses are above 350  $\mu$ m and P = 250 N and speciments, the sizes of wear products are above 350  $\mu$ m under P = 400 N. The surface layers of manganeses are above 350  $\mu$ m and P = 250 N and 40 µm under sizes of wear produces P = 400 N. The surface layers of manganese size and a range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. The surface layers of manganese size and range from 600 to 1000 µm under P = 400 N. specificities and separation of fragments steel are destroyed as a result of microcracking and separation of fragments of the material.

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#### ИССЛЕДОВАНИЕ ТРИБОТЕХНИЧЕСКИХ СВОЙСТВ высокоазотистых сталей после наводораживания

### Валерий Колесников, Александр Балицкий, Яцек Елиаш

Аннотация. Статья посвящена экспериментальным данным триботехнических свойств высокоазотистых сталей после наводораживания. Результаты трибологических испытаний выявили высоколеет продукции одежды после наводораживания намного выше, чем до наводораживания образцов (линейные размеры отличаются 5 - 6 разами). Также приведен краткий анализ литературных и интернет источников посвященных водородной стойки сталей

Ключевые слова: водородстойкая сталь, высокоазотистая сталь, нержавеющая сталь, продукты наноса.

### CONCLUSIONS

In the absence of hydrogenation, the sizes of wear products has range from 25 to 100  $\mu$ m under P = 500 N. For hydrogenation 25 to 100  $\mu$ m under P = 500 N. For hydrogenation 25 to 100  $\mu$ m under P = 500 N. In the absence of hydrogenation, the number P = 500 N. For hydrogenated  $40 \mu m$  under P = 400 N and from 40 to 100  $\mu m$  under P = 500 N. For hydrogenated  $40 \mu m$  under P = 400 N and from 40 to 100  $\mu m$  under a load P = 2500 matrix In the r = 400 N and from 40 to 250 µm under a load P = 250 N and P = 250 N and P = 200 N. The surface layers of manganese in N and specimens, the sizes of war products are above 350 µm under P = 400 N. The surface layers of manganese in N and specimens, the size of P = 400 N. The surface layers of manganese in N and specimens, the size of P = 400 N. The surface layers of manganese in N and specimens, the size of P = 400 N. The surface layers of manganese in N and specimens, the size of P = 400 N. The surface layers of manganese in N and specimens, the size of P = 400 N. The surface layers of manganese in N and specimens, the size of P = 400 N. The surface layers of manganese in N and specimens are specimens. 40  $\mu$ m under the sizes of wear products are 400 N. The surface layers of manganese size and specimens, the sizes of wear products of P = 400 N. The surface layers of manganese size and range from 600 to 1000  $\mu$ m under P = 400 N. The surface layers of manganese size and range from 600 to 1000  $\mu$ m under P = 400 N. The surface layers of manganese size and range from 600 to 1000  $\mu$ m under P = 400 N. The surface layers of manganese size and range from 600 to 1000  $\mu$ m under P = 400 N. specification of the story of t of the material.

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#### ИССЛЕДОВАНИЕ ТРИБОТЕХНИЧЕСКИХ СВОЙСТВ ВЫСОКОАЗОТИСТЫХ СТАЛЕЙ ПОСЛЕ НАВОДОРАЖИВАНИЯ

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KOMISJI MOTORYZACJI I ENERGETYKI ROLNICTWA POLITECHNIKI LUBELSKIEJ WSCHODNIOUKRAINSKIEGO NARODOWEGO UNIWERSYTETU IM. WOŁODYMYRA DALA W ŁUGAŃSKU

> COMMISSION OF MOTORIZATION AND POWER INDUSTRY IN AGRICULTURE LUBLIN UNIVERSITY OF TECHNOLOGY VOLODYMYR DAHL EAST-UKRAINIAN NATIONAL UNIVERSITY OF LUGANSK

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#### INVESTIGATION OF THE TRIBOLOGICAL PROPERTIES HIGH NITROGEN STEELS AFTER HYDROGENATION

#### Valerii Kolesnikov, A.I. Balitskii<sup>x</sup>, Jacek Eliasz<sup>xx</sup>

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**Summary.** The articles describes resultants experiments data of wear resistance high nitrogen steels after hydrogenation. The results of tribological tests revealed that the size of the wear products after hydrogenation is much higher than before the hydrogenation of samples (Linear sizes differ in 5 - 6 times). Also in the articles analyses literary and the internet sources devoted hydrogen resistant steels.

Key words: hydrogen resistant steels, high nitrogen steels, stainless steel, wear products.

#### INTRODUCTION

The operational stability of the industrial equipment is much determined by the intensity of deterioration of the interfaced surfaces, and up to 80 % of refusals of machines and mechanisms occur became of to deterioration of materials in units of friction [1, 2]. High nitrogen steels can be the perspective materials as a hydrogen resistant materials, including in the friction conditions. The problem of hydrogen wear up to this time still is not complete investigated, but some data it is possible to find in the papers [1 -8]. Hydrogen embrittlement is the process by which various metals, most importantly high-strength steel, become brittle and fracture following exposure to hydrogen. The mechanism starts with lone hydrogen atoms diffusing through the metal. At high temperatures, the elevated solubility of hydrogen allows hydrogen to diffuse into the metal (or the hydrogen can diffuse in at a low temperature, assisted by a concentration gradient). When these hydrogen atoms re-combine in minuscule voids of the metal matrix to form hydrogen molecules, they create pressure from inside the cavity they are in. This pressure can increase to levels where the metal has reduced ductility and tensile strength up to the point where it cracks open (*hydrogen induced cracking*, or HIC). High-strength and low-alloy steels, nickel and titanium alloys are most susceptible [3]. The purpose of work was to analyses literary and the internet sources devoted hydrogen resistant steels.

#### **OBJECTS AND PROBLEMS**

The wear resistance was measured in an SMT-1(2070) friction machine according the roller-shoe scheme under the conditions of boundary and dry friction. As the counterbody, we used a roller made of Steel 1.0503 (Germany) equivalent of 45 hardened steel with a hardness of 55...60 HRC and stainless steel (Cr = 11...15 %).

Hydrogenation of alloys was carried out at a current of 50 to 100  $A/m^2$  in a solution of sulfuric acid (26% H<sub>2</sub> SO<sub>4</sub>). The wear products were studied with a Neophot-2 microscope by treating the images of a Canon EOS 30D digital camera on a personal computer, and friction surfaces were examined with an EVO-40XVP electron microscope with an INCA Energy 350 system of X-ray microanalysis. The wear products of high-nitrogen austenitic steels and steel 45 were separated with a permanent magnet.

Num.	Grade	C	Cr	Mn	Si	Ni	V	Si	Mo	V	N
1.	Alloy No. 1 (DDT 68)	0.06	17.5	19.4	0.52	0.13	0.14	0.52	2.08	0.14	0.97

Table 1. Chemical Compositions of Steels and Alloys (wt. %)

#### CONCLUSIONS

The surface layers of manganese steel and stainless steel are destroyed as a result of microcracking (Fig.1) and separation of fragments of the material but not as a result of seizure.



b

Fig. 1. Friction surfaces stainless steel (counter-body (a roller)) of under the normal friction conditions (a). EDX – spectra of stainless steel fracture surfaces (b)



Fig. 2. Wear of alloys under conditions of dry friction under a load P = 450 N ((1) alloy No. 1 is steel 1,0503); (2) alloy No. 1 is stainless steel (immediately after hydrogenation)

The outward appearance of wear products is quite diverse, which provides evidence of different characters of fracture of the materials under study and, correspondingly, of their different wear rates. Subsequent experiments with these samples (with increasing time after hydrogenation), the wear rate is reduced (probably due to two factors: the running-in of samples and decrease the amount of hydrogen in the surface layer of the alloy). It is stated that the more loading increases, the more size of the wear products increases. For not hydrogenated samples it is  $25...40 \mu m$  (load 400 N),  $25...100 \mu m$  (load 500 N). For the hydrogenated samples size of particles is  $350 \mu m$  (with a load of 250 N), 600 microns (load 400 N). The morphology of the wear products is analyzed and described. Noted a significant difference in the appearance of wear particles of hydrogenated and not hydrogenated alloys.

The results of tribological tests revealed that the size of the wear products after hydrogenation is much higher than before the hydrogenation of samples (Linear sizes differ in 5 - 6 times) [2].



Fig. 3. Wear products: a) before hydrogenation; b) after hydrogenation

Taking into account the general laws of fracture of alloys (and taking the average statistical sizes of wear products) and applying the methods of mathematical statistics, one can establish the general structural-energetic criteria describing the interrelation of fracture intensity with the parameters of structural-phase composition and the sizes of wear products with regard for the external friction parameters (slip velocity and load) [4 -6].

We make brief review hydrogen resistant steels. The problem of hydrogen resistant steels is not complete

investigated, but some data it is possible to find in the papers [1-9].

In the internet references [10] the proposal concerns development of engineering materials for service in hydrogenating environments. The approach is based on the electronic concept of hydrogen embrittlement (HE), studies of atomic interaction between hydrogen and alloying elements in steel and the effect of alloying elements on hydrogen migration, hydrogen-induced phase transformations and mechanical properties of hydrogenated steels. It is shown that a reason for HE is the hydrogen-caused increase in the concentration of free electrons leading to a striking decrease of the shear module, which results in a strongly modified mechanism of plastic deformation leading to pseudo-brittle fracture. The developed concept is applicable for all not hydride-forming metals. The knowledge of optimal chemical compositions of hydrogen-resistant austenitic steels is obtained from the studies of Me-H bonding energies in the solid solution, mobility of dislocations, hydrogen migration enthalpy and hydrogen-induced phase transformations in relation to mechanical properties. In the papers



Fig. 4. Graphics: a) stress-strain curve of hydrogen-free and hydrogen-charged steels. Effect of Ni in a model steel; 6) effect of chemical composition on hydrogen migration enthalpy and hydrogen embrittlement of austenitic steels [10]

The tendency of hydrogen to localization should be considered as a major factor of hydrogen degradation. The localization of hydrogen allows significant changes in materials even at very low hydrogen concentrations. Effects arising at hydrogen concentrations in metals of the order of 0.1 - 0.01 at. % would not exist at all if its distribution were uniform [11]. Two effects different in nature are concerned with the factor of localization. The essence of the first one is that, in the already perfect crystalline lattice of metal, the presence of clusters [12, 13] in the form of a nearly periodic lattice of the protonic subsystem (electrons of hydrogen and the metal are collective), which is "dipped" into the lattice of the metal and has a lattice constant of order nearly identical to that of the metal [13], is more favorable in terms of energy rather than the uniform distribution of the dissolved hydrogen. This means that the atomic concentration of hydrogen in these regions of the phase enriched in hydrogen approaches 100%. This effect depends on the electron density of the metal and on temperature, since clusters become unstable and resolve at temperatures of about 500 K, i.e., when the effects of hydrogen embrittlement of metals disappear.

The other effect of hydrogen localization is *its segregation in defects of the crystalline structure* [14, 15, 16]. The importance of this effect for the behavior of materials is attributable to the fact that, on the one hand, it is structural defects, their structure, and properties that determine the properties of materials [11].

#### CONCLUSIONS

In the absence of hydrogenation, the sizes of wear products range from 25 to 40 | m under P = 400 N and from 40 to 100 | m under P = 500 N. For hydrogenated specimens, the sizes of wear products are above 350 | m under a load P = 250 N and range from 600 to 1000 | m under P = 400 N. The surface layers of manganese steel and stainless steel are destroyed as a result of microcracking and separation of fragments of the material but not as a result of seizure.

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#### ИССЛЕДОВАНИЕ ТРИБОТЕХНИЧЕСКИХ СВОЙСТВ ВЫСОКОАЗОТИСТЫХ СТАЛЕЙ ПОСЛЕ НАВОДОРАЖИВАНИЯ

#### Валерий Колесников, Александр Балицкий, Яцек Елиаш

Аннотация. Статья посвящена описанию данных экспериментов триботехнических свойств высокоазотистых сталей после наводораживания. Результаты трибологических испытаний выявили, что размер продукции одежды после наводораживания намного выше, чем до наводораживания образцов (линейные размеры отличаются 5 - 6 разами). Также приведен краткий анализ литературных и интернет источников посвященных водородной стойки сталей.

Ключевые слова: водородстойкая сталь, высокоазотистая сталь, нержавеющая сталь, продукты износа.

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Аннотация. Статья посвящена описанию данных экспериментов триботехнических свойств высокоазотистых сталей после наводораживания. Результаты трибологических испытаний выявили, что размер продукции одежды после наводораживания намного выше, чем до наводораживания образцов (линейные размеры отличаются 5 - 6 разами). Также приведен краткий анализ литературных и интернет источников посвященных водородной стойки сталей.

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