DETERMINATION OF ELASTOPLASTIC PROPERTIES AND POROSITY OF COMPOSITE NICKEL-IRON ROOFS

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Abstract: *This paper presents the elastic-plastic properties (he, hp; h; Ae; Ap; A; H; Hh; Hd, P) and define the parameters (Pcr; Hhcr; Hdcr) beginning of brittle fracture of iron-nickel composite coatings. First established experimentally that with the beginning of brittle fracture (Pcr = P), the work expended in elastic (Ae), plastic (Ap) and elastic-plastic (A) deformation significantly increases the load on the diamond spherical indenter (Pcr = P) and indentation depth (hp; h) decreases with increasing current density (DK) and a decrease in the electrolysis temperature (T). Critical load indentation (Pcr), not restored critical hardness (Hhcr) or the critical stress can be taken as a criterion for assessing the propensity of iron-nickel composite coatings to brittle fracture.*

Keywords*: elastoplastic, deformation, failure, galvanic, electrolytic, iron-nickel coatings.*

1. Introduction

The electro deposition of iron-nickel coatings are included in a large number of foreign particles significantly affect the structure of sediments, and consequently on their physic-mechanical properties. A high internal stress coating depends on the electro crystallization sediments. These features are the main reason for defining the properties of the coatings such as hardness, porosity, brittleness, fatigue strength of coatings [1].

Under the influence of internal stresses in the coatings appears porosity, which can be divided into three groups:

1) macro pores occur depending on coating structure which is influenced by the conditions of the electrolysis;

2) micro pores arise depending on the coating structure which is influenced by the conditions of the electrolysis;

3) pores type channel (grid cracks) arising from the presence of large internal stresses.

In all cases an increase of internal stresses in the coatings leads to an increase in porosity [1]. Formation of pores in the coating type channel promotes higher wear resistance of coatings with their work in conditions of lubrication lack.

Electrolysis conditions have significant impact on the density of the coating [1]. This is due to the change in porosity sediments. Perhaps that is why there are significant changes in elastic properties of coatings.

Ratio **Hh/H** is virtually independent of the nature of the distribution of pressure in the track, and is determined only by the average pressure, normalized to reduced contact modulus.

Analysis of elastic deformations in print followed by calculating the ratio of the reduced and unreduced hardness is important for the study and development of pilot test methods of the kinetic hardness and micro hardness. Attitude **Hh/H** - important experimental parameter, and its deviation from the calculated value can characterize such a necessary indicator for materials and hardening of the surface layers and coatings, as porosity. Analysis of this relationship is considered in a number of papers [2] which also find the displacement of two elastic bodies in contact (one of them is the indenter) the applied load is distributed over the area of the plastic print.

To estimate the porosity of the surface layers of the material proposed method assesses the degree of porosity of the material on his seal indentation. The seal appears to change the height of the roller around the indentation and leads a decrease in the ratio **Hh/H**. Hence for quantifying and seals need to measure both hardnesses (**Hh** - *unrestored hardness*, **H** - *restored hardness*). In the absence of material porosity ratio **Hh/H** in the first approximation should be constant.

Due to the high localization of the area of plastic deformation test with continuous registration process parameters indentation of a spherical indenter can give more information than a tension test at preserving its main advantage as a non-destructive method and express control of material properties.

One of the defining characteristics of the coating powder materials is their porosity (**ρ**), estimated as the general level, as well as the nature of the pore size distribution. The latter is very important because the pores which concentrate stress, remove the plastic properties of the material.

Influence of porosity on the indentation process depends on the size of the print. If the pore size and the distance between them is greater than the print size, the probability of entering the pores in the print zone, and hence the local fluctuation of density of the material subordinating static laws. If the print size appreciably larger than the distance between the pores, the fingerprint is stored in the average area density of the material depends on the total porosity of the material.

The total porosity of the indentation determines the change in the elastic modulus E and the ratio **Hh/H**.

The porosity of the material is determined by the formula:

$$\rho = 2(1-\kappa) \qquad (1)$$

where:

k - coefficient taking into accounts the degree of compaction of the material;

$$k=(H_h/H)^{0.5} \qquad (2)$$

where:

Hh - unrestored hardness;

H - restored hardness.

E value and **Hh/H** depend on the form of pores. Tapered pore according M.Krivoglaz give a lower modulus of elasticity **E**. In addition, they are easier to heal under the imprint area of the plastic, since spherical pores healing requires a higher degree of hydrostatic compression. In connection with these pores are easily compacted flattened and therefore have a low ratio whiter **Hh/H** and higher strain hardening coefficient.

In the paper, elastic-plastic properties and porosity characteristics of iron-nickel composite coatings obtained from the electrolysis of 4 [1, pp. 59]. The samples used in the rollers of diameter 30 mm, thickness 0.5 mm and the coating length of 100 mm, which were processed under optimal grinding.

Physical and mechanical properties were determined at the facility for the study of the hardness of materials in macro volume equipped with an inductive sensor and a differential amplifier allows you to record chart indentation diamond spherical indenter and indentation recovery after removal of the load [1].

2. Discussion of the experimental study.

These studies have shown that the investigated physical and mechanical properties of iron-nickel composite coatings varie with the electrolysis conditions (tables 1 and 2).

With increasing current density (**Дк**) of 5×10^{-4} to 80×10^{-4} kA/m^2 electrolysis at constant temperature (40^{0}C), plastic (**hp**) component of the indentation depth ratio **Hh/H** ratio which takes into account the degree of compaction (**k**), elastic modulus (**E**) decrease, respectively, from 0.866 to 0.650 (micrometers), from 0.433 to 0.325 (micrometers) and from 0.658 to 0.570 (micrometers), from 21000 to 17500 (N/mm^2), and the elastic component (he) indentation depth and density of iron-nickel coatings increase accordingly from 1.134 to 1.350 (micrometers), and from 0.684 to 0.800 (micrometers). The total depth of the indentation in this case was constant, and was 2 micrometers (N). Work expended in elastic (**Ae**), plastic (**Ap**), the total deformation (**A**) recovered hardness (**N**), unrestored hardness (**Hh**), indentation load spherical diamond indenter (**P**) are the extreme value with changes in current density (**Дк**) from 5x10^{-4} to 80x10^{-4} kA/m^2 electrolysis at constant temperature (40^{0}C).

These studies have shown that with increasing current density of 5×10^{-4} to 50×10^{-4} kA/m^2 electrolysis at a constant temperature (40^{0}C) the work expended in elastic deformation of the coating increases from 17.2×10^{-3} to 23.5×10^{-3} (N·mm), the work expended in plastic deformation of coatings increased from 13.2×10^{-3} to 13.8×10^{-3} (N·mm), the total work spent on elastoplastic deformation of coatings increased from 30.4×10^{-3} to 37.3×10^{-3} (N·mm). With further increase in current density from 50x10^{-4} to 80×10^{-4} kA/m^2 electrolysis at a constant temperature (40^{0}C), the work spent on the elastic deformation of the coating increases from 23.5×10^{-3} to 18.8×10^{-3} (N mm), the work expended in plastic deformation decreased from 13.8×10^{-3} to 9.0×10^{-3} (N mm), the total work spent on the elastic-plastic deformation of the coating decreased from 37.3×10^{-3} to 27.8×10^{-3} (N·mm). From the results of research can be seen that the work expended in elastic (**Ae**), plastic (**Ap**) and elastic-plastic (**A**) deformation of iron - nickel coatings have extreme character with a change of the current density (**Дк**) at a constant temperature electrolysis (**T**).

Elastoplastic properties and porosity of the iron-nickel composite coatings Table 1.

Electrolysis conditions		Elastoplastic properties						H, N/мм²	Hh, N/мм²	Hh/H	E, N/мм²	P, N	k	ρ
Дк, ×10⁻⁴ кА/м²	T, ⁰C	he, μм	Ae, N·мм	hp, μм	Ap, N·мм	h, μм	A, N·мм							
5	40	1,134	0,01723	0,866	0,01316	2	0,03040	8385	3630	0,433	21000	45,6	0,658	0,684
10	40	1,150	0,01767	0,850	0,01351	2	0,03073	8636	3670	0,425	20500	46,1	0,652	0,696
20	40	1,172	0,01863	0,828	0,01357	2	0,03180	9173	3800	0,414	19800	47,7	0,643	0,714
30	40	1,210	0,02017	0,790	0,01361	2	0,0333	10081	3980	0,395	19500	50,0	0,628	0,744
40	40	1,240	0,02137	0,760	0,01369	2	0,0347	10839	4120	0,380	19300	51.7	0,616	0,768
50	40	1,260	0,02356	0,740	0,01384	2	0,03740	12065	4470	0,370	18800	56,1	0,608	0,784
60	40	1,280	0,02020	0,720	0,01212	2	0,0337	11173	4020	0,360	18000	50,5	0,600	0,800
70	40	1,350	0,01577	0,650	0,00904	2	0,0278	10221	3320	0,325	17500	41,7	0,570	0,860

Elastoplastic properties and porosity of the iron-nickel composite coatings Table 2.

Electrolysis conditions		Elastoplastic properties						H, N/мм²	Hh, N/мм²	Hh/H	E, N/мм²	P, N	k	ρ
Дк, ×10⁻⁴ кА/м²	T, ⁰C	he, μм	Ae, N·мм	hp, μм	Ap, N·мм	h, μм	A, N·мм							
50	20	1,520	0,02113	0,480	0,00667	2	0,02780	13854	3320	0,240	17100	41,7	0,49	1,02
50	40	1,260	0,02356	0,740	0,01384	2	0,03740	12065	4470	0.370	18800	56,1	0,608	0,784
50	60	1,028	0,01563	0,972	0,01377	2	0,03040	7475	3630	0,486	20500	45,6	0,697	0,606

Character of change of reconstituted (**N**), unreduced (**Hh**) hardness and indentation load (**P**) on a spherical diamond indenter at a depth of 2 micrometers, with increasing the current density from 5×10^{-4} to 80×10-4 kA/m^2, electrolysis at a constant temperature (40ºC) has an extreme character (table 1).

With increasing current density from 5×10^{-4} to 50×10^{-4} kA/m^2, electrolysis at a constant temperature (40ºC), restored the hardness (N) increased from 8385 to 12065 (N/mm^2) are not restored hardness (НП) increased from 3630 to 4470 (N/mm^2), indentation load on the diamond spherical indenter increased from 45.6 to 56.1 (N). With further increase of the current density from 50×10-4 to 80×10-4 (kA/m^2), at a constant temperature electrolysis (40ºC) restored the hardness (N) decreased from 12065 to 10221 (N/mm^2), hardness is not restored (**Hh**) decreased from 4470 to 3320 (N/mm^2) and the indentation load on the diamond spherical indenter (**P**) decreased from 56.1 to 41.7 (N), Table 1.

With increasing temperature electrolysis (T, Table 2) at a constant current density (50×10^{-4} kA/m^2), from 20 to 60°C the plastic component (**$h_П$**), the depth of indentation ratio **Hh/H**, the modulus of elasticity **E**, and the power factor takes K into account to seal correspondingly increased from 0,480 to 0,972 micrometers, from 0.24 to 0.486, from 17100 to 2050 (N/mm^2), and from 0.490 to 0.697, and the elastic component (he) indentation depth recovered hardness (N) and the porosity of the coatings (ρ) decreased respectively from 1.520 to 1.028 (μm) from 13854 to 7475 (N/mm^2) and from 1.02 to 0.606.

Nature of the change work expended in elastic (**Ae**), plastic (**Ap**) and elastic-plastic deformation of iron-nickel coatings with temperature electrolysis from 20 to 60ºC at a constant current density (50×10^{-4} kA/m^2) has an extreme character. With increasing temperature electrolysis from 20 to 40ºC at a constant current density (5×10^{-4} kA/m^2), the work expended in elastic (**Ae**), plastic (**Ap**) and elastic-plastic deformation (**A**), respectively, increased from $21,1\times10^{-3}$ to $23,5\times10^{-3}$ (N/mm^2), from $6,7\times10^{-3}$ to $14,8\times10^{-3}$ (N mm) and of $27,8\times10^{-3}$ to $38,3\times10^{-3}$ (N mm). With further increase of the temperature of the cell from 40 to 60ºC at a constant current density (50×10^{-4} kA/m^2), the work expended in elastic (**Ae**), plastic (**Ap**) and elastic-plastic deformation (**A**) iron - nickel coatings decreased respectively by $23,5\times10^{-3}$ to $15,6\times10^{-3}$ (N mm), from $14,8\times10^{-3}$ to $13,8\times10^{-3}$ (N mm) and of $38,3\times10^{-3}$ to $29,4\times10^{-3}$ (N mm).

Nature of the change is not reduced hardness (**Hh**) and the indentation load diamond spherical indenter, at a depth of 2 micrometers, with an increase in temperature of the cell from 20 to 40ºC at a constant current density (50×10^{-4} kA/m^2) not restored hardness increased from 3320 to 4470 N/mm and the indentation load (P) of the spherical diamond indenter is increased from 41.7 to 56.1 (N). With further increase of the temperature of the cell from 40 to 60ºC at a constant current density (50×10^{-4} kA/m^2) unrestored hardness

(**Hh**) decreased from 4470 to 3630 (N/mm^2), and indentation load diamond spherical indenter decreased from 56.1 to 45.6 (N).

Studies have shown that the unreduced hardness (**Hh**), the work expended in elastic (**Ae**), plastic (**A**), elastic-plastic deformation, the load on the diamond spherical indenter (**P**, for **h** = 2 micrometers) have extreme character changes in the conditions of electrolysis (**Дк**, **T**) for the study of iron - nickel coatings and coincide with the earlier recommendations in terms of ensuring their optimum durability.

It is shown experimentally (Table 1 and 2) that the ratio **Hh/H**, the coefficient k - taking into account the degree of compaction and the modulus of elasticity (**E**) decreases with increasing current density (**Дк**) and low temperature (**T**). With increasing current density (**Дк**) and a decrease in the electrolysis temperature (**T**) increases the porosity of the material (**ρ**, Tables 1 and 2). This proves that the electrolysis conditions (**Дк**, **T**) have a significant effect on the density and porosity of iron - nickel coatings, which are in good agreement with the existing literature data.

3. Conclusion

It was established experimentally that the reconstructed hardness (**N**), unrestored hardness (**Hh**), the work expended in elastic (**Ae**), plastic (**Ap**) elastic-plastic deformation (**A**) and the load on the diamond spherical indenter (P, for h=2 micrometers) have the extreme nature of changes in the conditions of electrolysis (**Дк,T**) for the study of iron - nickel composite coatings.

First determined experimentally, taking into account the power factor of the seal material (k) and the porosity of the material (ρ) with the change in the conditions of electrolysis (**Дк**, **T**) iron - nickel composite coatings.

It has been established that the increase of the current density (**Дк**) and a decrease in temperature (**T**) of the electrolysis for the iron - nickel composite coatings factor takes into account the degree of compaction (k) decreases, while the porosity of the coatings (**ρ**) increases.

Extreme values of the reduced hardness (**N**), unreduced hardness (**Hh**), the work expended in elastic (**Ae**), plastic (**Ap**) elastic-plastic deformation (**A**), the load on the diamond spherical indenter (P) coincide with those obtained recommendations for iron - nickel composite coatings in terms of ensuring their optimum durability.

The method of measuring the hardness in the macro - the most amount reasonably and accurately determine physical - mechanical characteristics (**H**, **Hh**, **Ae**, **Ap**, **A**, **P**, **Hh/H**, **E**, **K**, **ρ**) iron - nickel composite coatings.

Physical - mechanical characteristics (**Ae**, **Ap**, **A**, **H**, **Hh**, **P**) composite iron - nickel coatings have good wear rate correlation with these coatings.

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