ABSORPTION OF HYDROGEN BY HIGH-STRENGTH STEEL AT CHEMICAL AND ELECTROCHEMICAL NICKEL PLATING AND VARIATIONS OF ITS FATIGUE STRENGTH

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Abstract

The residual stresses in nickel coatings are determined. In surface layer with the thickness 50 μm the concentration of hydrogen determined was by a anodic-photometric way. It has been established that concentration of hydrogen after electrochemical nickel plating in near-surface steel layer of 10 μm thick is of 3 times more than after chemical nickel plating. The fatigue resistance of high-strength steel after chemical and electrochemical nickel plating was studied. It is established, that the nickel plating reduces fatigue resistance. It is shown, that the heat treatment of steel after a chemical nickel plating lowers fatigue resistance. The electrochemical nickel plating of steel in the presence of benzyltributylammonium chloride allows to increase its fatigue resistance approximately by 23% as contrasted to nickel plating in an electrolyte without the additives.

Keywords: hydrogen enrichment, fatigue, electrochemical nickel plating, chemical nickel plating, stresses, high-strength steel

Introduction

Protection of workpieces against corrosion is one of the leading factors of applying of plating. However after plating the mechanical properties of workpieces change. Especially this phenomenon is characteristic for a nickel plating and chromizing. The electrodeposition of metals results to charging with hydrogen of a deposit and base metal, that degrades their mechanical properties, Vagramjan [1], Vajner [2], Cotterill [3], Kim [4]. Quantity of absorbed hydrogen in most cases were determined by heating in vacuum. The drawback of this method is that the common desorbed gases quantity is taken into account and then the hydrogen quantity in the whole specimen. The nickel plaitings reduce in a very strong degree, in particular, fatigue resistance of high-strength steels, Beloglazov [5]. Earlier Slezhkin [6] and Beloglazov [7] showed, that the reason of a decrease of fatigue resistance is determined by high tensile stresses arising in coatings at electrodeposition, and also by hydrogen absorbed by steel at an electrolysis, and concentrated in a near-surface layer.

As the metal destruction starts with a surface, its behaviour in many respects determines mechanical properties of metal and, in particular, fatigue resistance. In this connection the present activity is dedicated to research of absorption of hydrogen by high-strength steel at a chemical and electrochemical nickel plating in near-surface layers of steel, definition of residual stresses in nickel coatings and role of these factors in a decrease of fatigue resistance of steel.

Experimental

Electrochemical nickel plating was conducted in a sulphate electrolyte, modified with organic components, , composition (g/L): $NiSO_4{\cdot}7H_2O$ - 140; $Na_2SO_4{\cdot}10H_2O$ - 40; $MgSO_4$ - 25; H_3BO_3 - 20; NaCI - 5; pH=4,8... 5,0; T = (293... 353) K. The cathode current density 100 А/м^2. The chemical nickel was deposited from solution containing (g/L): $NiCI_2$ - 30; NaH_2PO_2 -15; CH_3CONa - 15; pH 4,0 … 5,0; T=(360 … 365) K. Concentration of hydrogen in steel determined by anodic-photometric method, Kliachko [8]. The residual stresses were measured by a method of a bending of the flat steel cathode and calculated on a technique [9]. The fatigue multiticycle tests of flat specimens made of high-strength steel (composition, %: 0,62 C; 0,98 Mn; 0,32 Si and 0,2 Cr), with the thickness of 1,0 mm. The specimens were carried out by simmetrical bending at the frequency of 90 Hz at the experiment basis of $2{\cdot}10^6$ cycles [9].

Results and discussion

At a chemical nickel plating the initial state of process is disintegrating hypophosphite on a catalyzing surface of metal with formation of an atomic hydrogen. Further atomic hydrogen participates in reduction of an ion Ni^{2+} up to an atomic nickel. Simultaneously there is a partial recovery of a hypophosphorous acid up to elementary phosphorus, which both of steel basis, and coating, that is affirmed by the results, showed in Fig. 1. As it is visible from a course of the schedules, hydrogen is distributed non-uniformity across the depth of steel, focusing predominantly in a subsurface metal layer with the thickness 40 … 50 μm. Heat treatment of specimens within 2 h at 473 K results in some decreasing of the contents of hydrogen, however in a layer 30…40 μm thick its concentration remains high enough.

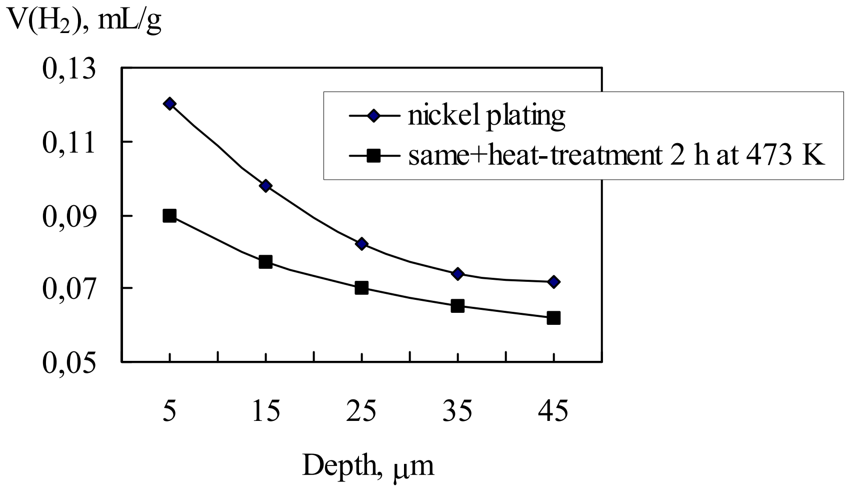

Fig.1. Distribution of hydrogen across of surface layer of the steel base after chemical nickel plating 20 μm thick.

At the chemical nickel plating the coating is reshaped with high residual stresses by stretching reaching 280 MPa (Fig. 2). The fatigue tests (Fig. 3) have shown, that results the chemical nickel plating reduces endurance limit of steel. It is conditioned by pressure by stretching in nickel coating and the high contents of hydrogen in near-surface layers. It is necessary to mark, that fatigue strength hardly decreases in the field of restricted durability. Heat treatment nickel plated specimens within 2 h at 473 K also reduces fatigue strength. The heat treatment results in increase of adhesion with base metal, and also leads to formation in nickel coating of a brittle phase Ni_3P. Therefore at a repeated deformation the destruction of coating is accelerated, that results in formation of concentrators of pressure accelerating destruction of base metal.

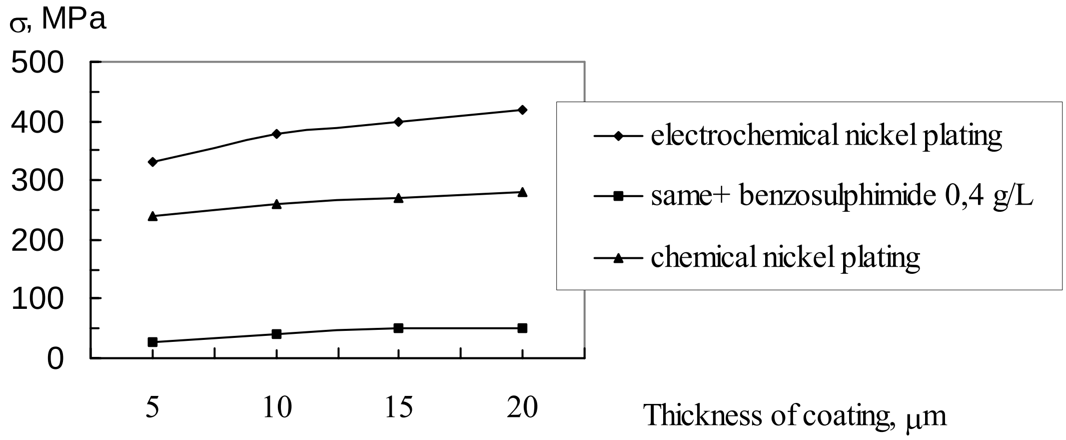

Fig. 2. Residual stresses in nickel coating.

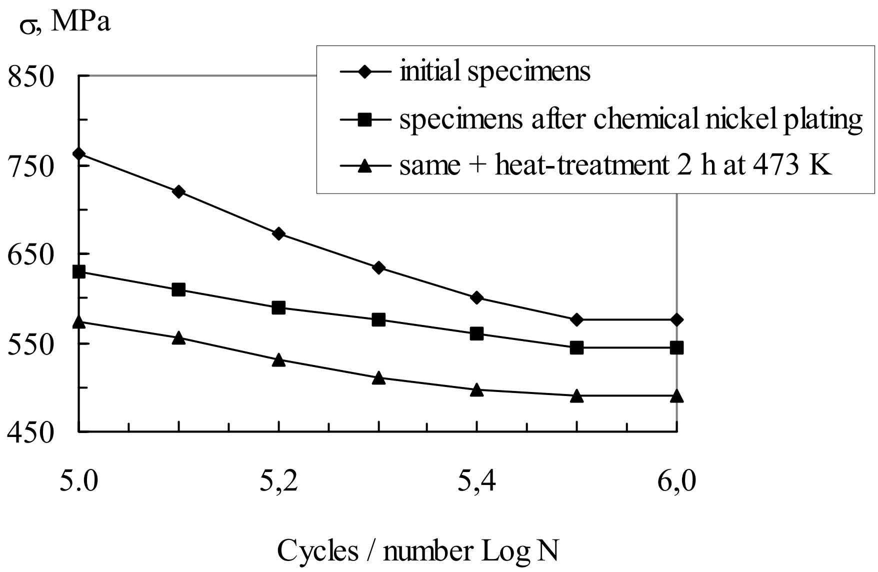

Fig. 3. Curves of fatigue of specimens after chemical nickel plating.

The processes of electrochemical nickel plating and chemical nickel plating are accompanied by hydrogen charging of coating and steel base. The distribution of hydrogen across of steel specimens is shown in Fig. 4. From charts it is visible, that hydrogen in a large degree is massed in subsurface metal layer with thickness 40 … 50 μm. The surface layer of metal always contains a lot of defects, than layers arranged in depth. It can explain the large hydrogen content of near-surface layers both in case of a chemical nickel plating and in case of an electrochemical nickel plating.

The change of residual stresses in nickel coating during electrolysis is shown in Fig. 2. From the charts it is visible, that by increase of thickness of coating there is some increase of residual stresses of stretching. The introducing in an electrolyte of a nickel plating of benzosulphimide results in decreasing tension stresses approximately 8 times.

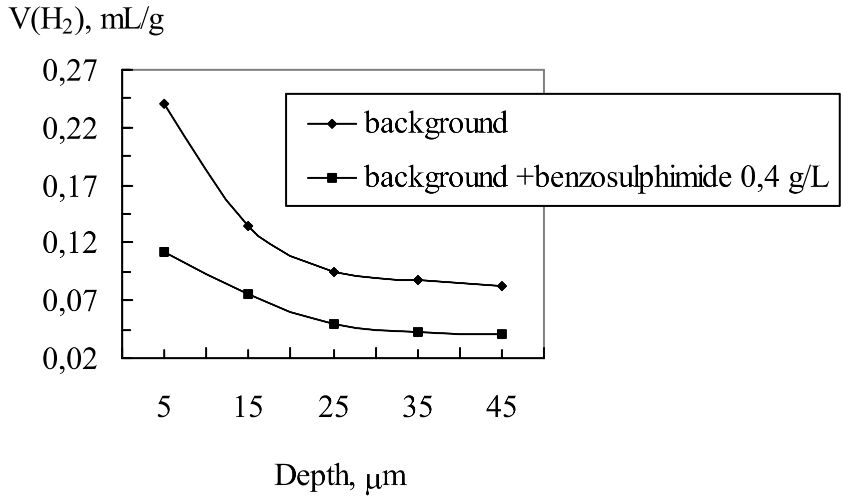

Fig. 4. Distribution of hydrogen across of steel base after electrochemical nickel plating 20 μm thick.

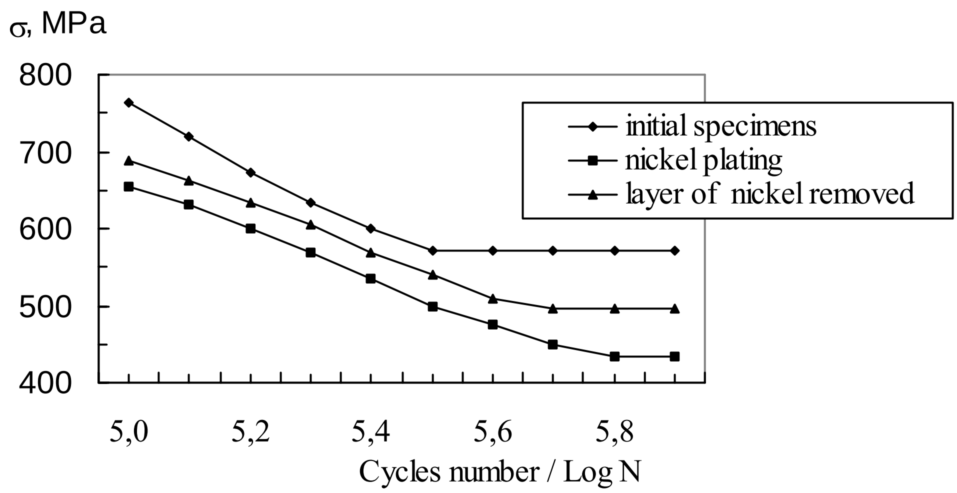

Fig.5. Curves of fatigue of specimens after electrochemical nickel plating.

The availability in nickel coating of high tensions of stretching and large concentration of hydrogen in near-surface layers results in essential decreasing of fatigue resistance of steel (Fig. 5). A nickel plating of specimens in the presence of benzosulphimide results in essential increase of fatigue resistance. However initial strength is not reached. It is conditioned by two reasons. At first, in surface layer remains there is hydrogen, though and in smaller quantity. Secondly - at a repeated deformation the diffusion of hydrogen in a zone of maximum stresses is watched. Therefore in a zone of destruction in surface layer the contents of hydrogen is augmented many times [9].

We conduct electrodeposition of a nickel in the presence of benzyltributylammonium chloride (B). The outcomes of experiments have shown, that in this case electrodeposition of a nickel is accompanied by essentially smaller charging of a steel base with hydrogen (Table 1). The contents of hydrogen decreases approximately 4 times at concentration of benzyltributylammonium chloride 1,0 mmol/L. The fatigue resistance thus increases up to

545 MPa. In spite of the fact that the tension stresses were increased up to 250 MPa. The simultaneous presence in electrolyte of benzyltributylammonium chloride and benzosulphimide results in formation of coatings with compressive stresses. Thus the availability in an electrolyte of benzosulphimide has a little effect on charging with hydrogen of a steel base. In this case increased the limit of fatigue resistance is, apparently, first of all due to transforming of tension stresses to compressive stresses.

Table 1
Influence of benzyltributylammonium chloride (B) concentration on the residual stresses by Ni-plating (σ), content of hydrogen (V_{H2}) in a near-surface layer 10 μm thick and limit of fatigue resistance (σ_{-1}); mode of electrolysis: T=323 K, i=150 A/м^2

Concentration (B), mmol/L	σ, MPa	V_{H2}, ml/g	σ_{-1}, MPa
-	210	0,31	440
0,25	88	0,28	445
0,5	135	0,20	460
0,75	195	0,16	465
1,0	250	0,08	540
0,5 +0,2 g/L benzosulphimide	-60	0,075	545

Conclusion

It has been established that both chemical and electochemical nickel plating brings about uneven steel hydrogenation. The basic hydrogen contents occur in the surface layer with the thickness of 40…50 μm. The fatigue strength decrease of high strength steel is mostly due to metal base hydrogenation to a much lesser degree by tensile stress in a nickel plating. It is shown that hydrogenation of the steel base at electrochemical nickel plating can be sufficiently reduced by investing. Electrochemical nickel plating of steel in benzyltributylammonium chloride makes it possible to increase its fatigue strength by 23% as compared to that of electrolyte without any organic additives. Heat treatment of the specimens after chemical nickel plating results in reduction of steel strength.

References

[1] A.T. Vagramjan, J.S. Petrova, Physical-mechanical properties of electrodeposits, AN SU Moscow, (1960).
[2] J.V. Vajner, N.A. Dasojan, Technology of electrochemical coatings, Machine building Engineering, Leningrad, (1972).
[3] P. Cotterill, Hydrogen embrittlement of metals, Metallurgy, Moscow, 1963.
[4] Y.G. Kim and Aleshka J, Metallurgical Transaction, **6A_** (1975) 1461.
[5] S.M. Beloglazov, Hydrogenation of steel at electrochemical processes, LGU (Leningrad), 1975.
[6] V.A. Slezhkin, Corrosion and Protection of Metals (SU), **4,** (1978), p. 98.
[7] S.M. Beloglazov, V.A. Slezhkin, Corrosion and Protection of Metals (SU), 5, (1980), p. 54.
[8] I.A. Kliachko, I.J. Shklovskaia, I.A. Ivanova, Factory Laboratory (SU), **9**, (1970), p. 1089.
[9] S.M. Beloglazov, V.A. Slezhkin, Corrosion and Protection of Metals (SU), **3,** (1977), p. 91.