ANALYSIS OF THE DC01 STEEL’S SURFACE DEPENDING ON THE RESISTANCE TO CORROSION AND THE ADHESION OF METALLIC LAYERS TO THE METAL STRUCTURE OF MEDICAL EQUIPMENT

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The dissertation focused on the analysis of surface layer of steel substrate and metallic coatings applied to DC01 and RS037-2 NBK steel, as well as the corrosion resistance of the applied coatings. Selected research materials, DC 01 and RS037 2 NBK, are very often used in the manufacture of medical equipment such as rehabilitation beds, trolleys, surgical tables, screens and bedside cabinets.

Observations made in units of health care, permit the conclusion that the construction elements of the medical equipment are protected by paint coatings as well as metallic nickel-chrome coatings. During long-term operating and maintaining of aseptic medical equipment there is a significant reduction in the corrosion resistance of galvanized coatings. It particularly relates to areas with difficult accessibility where cleaning, despite the use of aggressive disinfectants, is not easy. These areas often contain residues of food, drink, expectoration as well as blood. All these factors have a devastating impact on the protective coating, leading to the appearance of corrosion.

The research revealed that corrosion is a favorable condition for the deposition of dangerous bacteria and fungi. Therefore, the study selected standard protective coatings (nickel-nickel-chromium, nickel-chromium) as well as antibacterial properties, nickel-copper and copper without a sublayer. The research focused mainly on the properties of selected anti-corrosive galvanic coatings. The results allow for a better choice of the protective coating when designing medical equipment in terms of protection against corrosion and bacteria.
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<td>BHI</td>
<td>Brain Heart Infusion</td>
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<td>DC 01</td>
<td>steel in the form of cold-rolled sheet</td>
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<td>$E$</td>
<td>electrode potential</td>
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<td>EDS</td>
<td>energy dispersive spectroscopy</td>
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<td>$E_{CA}$</td>
<td>potential of the cathode-anode transition</td>
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<td>$E_{cp}$</td>
<td>critical passivation potential</td>
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<td>$E_{np}$</td>
<td>potential nucleation (initiation) pitting</td>
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<td>$E_p$</td>
<td>potential passivation</td>
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<td>$E_{cor}$</td>
<td>stationary potential (corrosion)</td>
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<td>HV</td>
<td>Vickers hardness scale - the scale for metals marking</td>
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<td>$i_{iop}$</td>
<td>cathodic current density at -750 mV potential</td>
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<td>$I_{kor}$</td>
<td>corrosion potential</td>
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<td>$i_{kor}$</td>
<td>corrosion current density</td>
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<td>$i_{rp}$</td>
<td>critical current density of passivation</td>
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<td>$i_{kp}$</td>
<td>critical current density</td>
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<td>$i_p$</td>
<td>passivation current density</td>
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<td>ISO</td>
<td>International Organization for Standardization</td>
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<td>$l_t$</td>
<td>the total length of the section profile</td>
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<td>$1kgf$</td>
<td>one kilogram-force (page 33 - hardness measurement)</td>
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<td>$Mr_1$</td>
<td>material part, determined by the intersection of the line separating the</td>
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<td>hills protruding from the roughness core profile</td>
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<td>$Mr_2$</td>
<td>material part, determined by the intersection of the line separating the</td>
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<td>deep recesses of the roughness core profile</td>
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<td>PN-EN</td>
<td>Polish standard complies with the requirements of European standard</td>
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<td>Ra</td>
<td>arithmetical mean deviation of the roughness profile</td>
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<td>Rk</td>
<td>core roughness depth</td>
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<td>Rp</td>
<td>polarization resistance</td>
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<td>$R_{pk}$</td>
<td>reduced height of hills</td>
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<td>R$t_5$</td>
<td>circular tube welded precision annealed by</td>
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<tr>
<td>$R_{k}$</td>
<td>reduced depth of the the recesses</td>
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<td>$Rz$</td>
<td>roughness parameter – an arithmetic mean height of the five highest hills</td>
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<td></td>
<td>above the line of the average reduced by the mean of the five lowest</td>
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<td>recesses below the average</td>
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<td>SBF</td>
<td>artificial blood</td>
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<td>$U_A$</td>
<td>potential of the anode</td>
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<td>$U_k$</td>
<td>cathodic potential</td>
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<td>Ca</td>
<td>calcium</td>
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<td>Cl</td>
<td>chlorine</td>
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<td>iron</td>
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<td>hydrogen</td>
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<td>NaCl</td>
<td>sodium chloride</td>
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<td>sodium hydroxide</td>
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<td>sulfur</td>
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<td>Si</td>
<td>silicon</td>
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<td>SO₂</td>
<td>sulfur dioxide</td>
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The current development of technologies in the field of metallic coatings and painting is very advanced. However, researchers are still looking for better solutions, particularly in the area of medicine and dentistry [1-4].

Observations made in health care revealed that the structural elements of the medical supplies-type operating tables, beds and bedside cabinets have protection on their surfaces in the form of galvanic coatings made of precious metals such as nickel and chrome or painting. During an operation, the maintenance of hygiene standards and long-term use, followed by degradation of galvanic coatings as corrosion increased [5,6]. You can see the intense local corrosion in the form of "outbreaks" in locations which are hard-to-reach when trying to maintain purity. The influence of chemicals – disinfectant, for example has an effect on the spread of corrosion causing further damage to the coating (Fig. 1).

![Fig.1 An operating table with the place of the corrosion [from own investigations]](image)

The available literature does not contain a lot of information on the corrosion of the equipment used in the area of hospital usage [7, 8].

Long-term exploitation of these devices and structures in disruptive and difficult conditions, results in them also being exposed to mechanical action, and further damage to the protective coating (chromium-nickel).

In this area we also have to deal with corrosion caused by body fluids like urine, blood, saliva, sweat, etc.

The formation of "outbreaks" of corrosion and their random spread causes subsidence and growths of bacteria such as colon bacillus (Latin Escherichia coli), Pseudomonas (Latin Pseudomonas aeruginosa), Staphylococcus aureus (Latin Staphylococcus aureus) and others [9].

Placement of microorganisms in niches, void and metallic coatings with an already existing corrosion causes an electrochemical corrosion phenomena that can also be linked by microbial corrosion [10-14].
2. LITERATURE REVIEW

2.1 Characteristics of the selected types of corrosion of metals

CORROSION PHENOMENA

Corrosion is labelled as a physic-chemical and electrochemical interaction between metal material and the surrounding environment, which causes the corrosion damage which then results in a reduction of metal properties. Due to the type of reaction, causing a destruction of metal or alloys can be made by the primary division of the corrosion of metals and alloys for the chemical and electrochemical interaction.

Sometimes, corrosion is accompanied by a physical phenomena of erosion, friction or a consumption of cavitation. In such cases, the combined effects of physical and chemical factors, the phenomenon of the destruction of metals are referred to respectively as erosion corrosion (corrosion-erosion), fretting corrosion or cavitation corrosion. The basic definitions of the concepts related to the corrosion of metals and alloys contains standard PN-EN ISO 8044:2002 [15, 16].

2.1.3 Electrochemical corrosion

ELECTROCHEMICAL CORROSION MECHANISM

Most corrosion processes are electrochemical. The surface of any metal or alloy can be thought of as a collection of positive and negative electrodes, short compact by (Fig. 2). Between these electrodes, which are the elements of the structure of metals or alloys, there is a difference of potentials. When the metal is threatened by the electrolyte, which can be water or aqueous solutions of salts, acids and alkalis, displaying the local micro-cell and the local flow of electric current. This is accompanied by chemical reactions reduction and oxidation.

A chemical reaction reduction (cathodic reaction) occurs on the electrode called the cathode and is related to the flow of a positive solution of current contractual electrolyte to electrodes (that is, in fact, electrons flow in the opposite direction), for example:

\[ \text{Cu}^{2+} \rightarrow \text{Cu} + 2e^- \]

The electrode called the anode oxidation chemical reaction proceeds (anodic reaction) connected with the movement of positive electric charges from the electrode to the electrolyte, for example:

\[ \text{Zn} \rightarrow \text{Zn}^{2+} + 2e^- \]

Fig.2 An arrangement diagram of the local corrosion cells on the surface of the metal [15]

8
Fig. 3 A diagram of the processes taking place on two electrodes during the corrosion of iron in acid solution (according to A.G. Guy) [15]

Whilst the flow of electric current is occurring so does the flow if ions, wherein cations such as H\(^+\), Fe\(^{2+}\), tend to cathode, while anions e.g. Cl\(^-\), OH\(^-\), SO\(_4^{2-}\), tend to anode.

As a result of electrochemical processes occurring in the micro-cells on the surface of the metal of electrolyte subjected to the action, the process of the corrosion runs. Corrosion occurs only on anodes micro-cells where salts or hydroxides of metals deposited on the electrode or passing through to the solution usually form (Fig. 3). During the corrosion of the positive and negative electrode, surfaces continuously change their position. Thus, galvanic corrosion can also be uniform.

**POTENTIOSTATIC POLARIZATION CURVES**

The passivation of metals and alloys is characterized by the potentiostatic polarization curve, obtained from potentiostat that specifies the relationship polarization current and electrode potential of the investigated metal which is relative to the standard reference electrode. For example - potentiostatic anodic polarization curve of iron in normal aqueous a sulfuric acid solution is shown in Figure 4. The potential is lower than the potential of the passivation P of iron although Fe is active, corrosive anodically to Fe\(^{3+}\). Increasing the potential to a value P, which corresponds to a critical current density \(i_{kryt}\), causing a jumping decrease in the current density to a value corresponding to a current density of passivation \(i_{pas}\). A further change in the value of the equilibrium potential, about 1.7 V, does not change the current density, and the corrosion products are the Fe\(^{3+}\) ions in the compounds in the form of a very thin passive film.

The substantial increase in electrode potential than the equilibrium value, so called, over potential of oxygen evolution, causes an increase in the oxygen evolution, which is related to the corrosion rate which is significantly higher than the lower potential of the electrode. This phenomenon is called transpassivity [17].
2.2 A study of corrosion resistance, electrolytic coatings

Corrosion resistance is a feature that primarily determines the suitability of coatings for corrosion protection in the foreseeable conditions of use. A corrosion test of both coatings and metal rely on samples of its action more or less of natural or artificial composite corrosion environment, which the components interact chemically, electrochemically and mechanically to metal or a protective coating.

ELECTROCHEMICAL STUDIES

Electrochemical methods are the subject of many formerly conducted researches and due to the possibility of obtaining information on the corrosion resistance of metals and protective coatings in less time than on the basis of the previously discussed studies [18-21].

For the measurement of the speed of corrosion of metal coating the method seems to be the most useful in the analysis of the polarization curve near the corrosion potential, allowing for the calculation of the corrosion rate in your environment as a corrosive loss of mass test of metal in the unit of time.

Basic electrochemical studies rely on:
- recording polarization curves anodic and cathodic resistance methods, extrapolation Tafel, polarizing of the inflection of the curve of polarization. It also serves to determine the corrosion current density and speed of general corrosion of metals and alloys in a specific environment,
- recording polarization curves anodic especially useful for studies of metals and alloys in order to determine the corrosion rate in the passive state, the passive range and the capacity of the building pitting,
- maintaining a constant anode potential for accelerated tests of stress and intergranular corrosion, and to test corrosion inhibitors and metal coatings [22].

Curves showing the dependence of the potential of the electrode of DC passing through the phase boundary metal-electrolyte, that is, curves, allow for the designation of corrosion current density of the layout. Due to the applied research technique for polarization curves are divided into:
- potentiokinetic (potentiodynamic), the electrode potential $E$ is changed over time in accordance with a given program, and current $i$ (constant current) is recorded as a function of the potential $E$.
- galvanokinetic, in which the external current $i_e$ changes over time according to a specified program, and the electrode potential $E$ is recorded in the current function $i_e$.
- potentiostatic, in which the applied electrode potential has a fixed value of $E$, and current $i_e$ is recorded as a function of time $t_e$.
- galvanostatic, in which an external constant current is tested and changes of the electrode potential $E$ is as a function of time $t$ [22].
The primary object of study, build, operations (in the manufacturing process) and of wear (in the process of exploitation) is the surface of a solid. Solid surfaces have a different structure and properties compared to the core material. This difference is mainly due to:

- a separate energy state, as a result, there is a higher status and increased surface energy adsorption activity [23],
- overlapping influences of mechanical, thermal, electrical, physical and chemical properties on the surface during the treatment of the subject,
- cyclic: mechanical, thermal, chemical and physical influences surrounding the object medium to the surface of the object during usage.

The surface affects substantially the useful properties of objects and products. A range of physico-chemical phenomena, such as: chemical catalysis, corrosion, wear and tear (abrasive, adhesive, adhesive-abrasive, erosion, cavitation, fatigue, by oxidation, by peeling), adhesion, adsorption (physical and chemical), and flotation depends on what shall be made on the surface of the material or its participation [24].

The concept of a surface is difficult to precisely define and understand. Usually, the concept of a surface is defined differently and ambiguously - depending on the discipline of science and technology for the purposes of which it is used.

In force since 1987 the Polish Standard PN-M-04250: 1987 (Surface Layer Terminology) does not distinguish the concept of coatings, including the term “surface layer”. The coating may comprise of a surface layer, superimposed on another, previously formed or produced, the surface layer. This is blurring the important differences (in terms of the properties construction, manufacture) between typical conventional surface layers and coatings.

Therefore, the distinction between the concepts adopted: the surface layer and coating, which then are assigned to them the general name - the surface layers (Fig. 5) [25-28].

![Fig.5 A schematic representation of the surface layers [32]](image)

The narrower, close sense of the word - is the physical surface interphase area (interphase area) solid - gas (liquid), more - shall include a the surface layer, in a very broad - Also coating. The surface layers are broadly understood as a physical surface.

As the coating is made from a different material than the core, it is essentially imposed on the other core material (the surface layer). Thus, the coating has its own physical surface.
THE CONSTRUCTION OF THE SURFACE LAYER

The surfaces of solids are always a reflection of methods for their form, e.g. crystallization (the smelting and casting of), deformation (the treatment of plastic) deformation and heat influence (by the machining), diffusion (the thermochemical treatment). Every surface, regardless of how it is formed, is characterized by a certain state of inequality.

The geometry of a surface, including the surface irregularities depends on the type of machining operation. Surfaces machined by turning, grinding and polishing, show a distinct traces processing (mapping the shape and route tools) in the form of repeated irregularities. Even the most accurately machined surfaces are irregularities in height 0,01-0,1 µm, roughly squared - even more than 1000 µm (e.g. after turning coarsely ductile materials thickness of the surface layer than 1000 µm [29, 30].

The shaped surface layer is always construction and the properties depend on the type of core material (chemical composition and physico-chemical properties), and the type and parameters of the machining operations. Because for the specified factor of first core material can be very different, and may also be associated with machining operations, while the second can be varied within its wide borders - it is difficult to establish an overall regularity of the structural surface layer, a general model of the structure surface layer.

For example, models surface layers after machining differ mainly in the degree of detail, taking into account the number of different phenomena. They share however the stratified construction: a multi surface layer which consists of several, often imperceptibly crossing one into the other with different structures and properties, called zones of the layers.

The outer zone (surface layer) is a layer of particles of foreign origin (material particles anti-surface tool or friction, cutting fluid, grease, sweat, dirt, dust, etc.) sapling particles mixed with the core material. The outer zone is covered from the surrounding medium layer of adsorbed gases: oxygen, nitrogen and water vapor. The thickness of the outer layer is 0,001-0,02 µm coating gas - about (2-3) \(10^{-4}\) µm.

The central zone (layer on the surface ) consists of strongly crushed grains of the core material and in many cases can be clearly textured. Thickness ranges from 0,5-500 µm. From the construction of the zone there are mainly physical properties of the surface.

The inner zone (subsurface layer ) consists of a particle which is not deformed plastically, but having a structure different from the material of the core, e.g. as a result of the changes taking place under the influence of heat. The inner zone is back to internal stress. The inner zone passes the core in an elusive way. Her thickness can be up to several thousand microns [31].

THE GEOMETRIC STRUCTURE OF THE SURFACE

The stereometric structure surface of the material at a specific construction is dependent on the structural machining operation. It constitutes kinematic-geometric representation.

A stereometric structure of the surface layer affects a very significant effect on the operating features: resistance to wear by friction (friction force and the lapining time), connections to the contact stiffness, fatigue resistance, thermal conductivity, emissivity, flow resistances and tightness [32, 33].

PARAMETERS OF SURFACE A OF THE LAYER OF FUNCTIONAL PROPERTIES

The surfaces of the tiered functional properties devoted to ISO standard consists of three parts:

-Part 1 [PN-EN ISO 13565-1: 1999] applies filtering and general measurement conditions,
-Part 2 [PN-EN ISO 13565-2: 1999] defines the parameters determined from the linearization of the curve part of the material,
-Part 3 [PN-EN ISO 13565-3:2002] defines the parameters determined from the present cumulative distribution function of material participation on the mesh of the normal distribution.

Surfaces with tiered functional properties characterized with deep pits in the surface of a precisely machined surface layer. With this type of filtering a surface roughness typical filter occurs unwanted effects disturbing profile.

Therefore a defined special two-step filtering procedure. In the first step of the primary profile there are deep recess cut in to the profile (at the average line obtained after filtration Gaussian filter). The modified profile is re-filtered by the Gaussian filter to give an average line profile. After the “straightening” of the original profile based on the average roughness profile obtained line.

Group parameters designated on the basis of material participation curve linearization (Fig.6):
Fig. 6 A figure for the definition of parameters: Rk, Rpk, Rvk, Mr1, Mr2, A1, A2

- Rk — core roughness depth,
- Rpk — reduced peak height,
- Rvk — reduced valley,
- Mr1 — component relative to peaks — designated by the intersection of the line separating the protruding peak core profile roughness,
- Mr2 — material component relative to valleys — designated by the intersection of the line separating the deep recesses of the core, the roughness profile,
- A1 — reduced peak area,
- A2 — reduced valley area.

For the roughness core profile it means a roughness profile without distinctive hills and deep pits. The procedure to determine the above parameters is as follows. A simple linearization is determined for the central area of the curve.

Procedure to determine the above parameters is as follows. A simple linearization is determined for the central area of the curve part of the material, comprising of 40% of all the measured points profile. This area is located in the place where the secant includes 40% of the material which shows the smallest inclination (if there are several areas of the same inclination, then select the first one). Simple linearization is determined on the method of least squares. Parameters Rpk and Rvk calculated as the amount of surface right triangles equivalent surface, respectively the surface hills and surface pits. Similarly Mr1 parameters and Mr2 are the foundations of these triangles (Fig. 6) [34].

In the simplest case the isometric image of the surface is achieved by the profilographing at intervals of several to tens of micrometers. The obtained information can then describe the parameters or functions analogous to those previously discussed, but defined in three-dimensional space [34].
5 GENERAL CHARACTERISTICS OF THE PROCESS OF ELECTROLYTIC DEPOSITION OF METALS AND THE IMPORTANCE OF PROPER SELECTION OF COATINGS

An application of electrolytic processes for metals should be then, when it comes to getting the clear coating, single or multilayer, rather small and usually not exceeding a thicknesses regulated exactly by tens of micrometers, for relatively small areas.

A proper selection of the coating determines the possibility of imposing it at the lowest cost of production, while ensuring the required quality of the surface covered and predicted useful life products.

Properly selected and properly made galvanic coating contributes to the overall improvement of the quality of the products, their proper and reliable operation and to prolong the time of their use.

The most important benefits arising from the use of electrolytic metal deposition methods in comparison with other methods are:

1) the uniformity of a large coating obtained,
2) the possibility of obtaining the desired thickness of coatings (in a relatively wide range),
3) a low temperature bath (not exceeding the boiling point of water),
4) relatively small porosity derived coatings,
5) high fineness imposed coatings,
6) the possibility of strict control of deposition process,
7) a small loss of embedding metal,
8) the ability to embed many metals and alloys as coatings single-and multilayered,
9) the possibility of obtaining different coatings and applications of different corrosion resistance suitable for the environment in which they are to be used,
10) a good adhesion of coatings,
11) high speed coating,
12) the ability to automate the process of [35].

CLASSIFICATION OF GALVANIC COATINGS, DEPENDING ON THEIR DESTINATION

Shell applied in practice can be divided into the following groups:

1) protective coatings - with the task solely to protect the base metal from corrosion,
2) decorative coatings - applied to improve the surface appearance (color, gloss, smoothness),
3) protective, decorative coatings – used as a protection against corrosion and put into effect at the same time preserving the decorative metal surface properties of substrate,
4) shell (functional)-used in order to obtain certain physical properties of the surface or technological, for example. increased resistance to abrasion, changing the coefficient of friction, to improve the electrical properties of the surface, to improve the ability of connecting by soldering, changing dimensions covered parts, used, surface regeneration increased the degree of reflection and luster surface, the security referred to in other surface treatment processes at run-time and getting thick layers in galvanoplasty.

Classification from the point of view of the protection mechanism of metal substrate for coating:

1) anodic coating - made of metal, which within a specified corrosive environment has the potential which is lower than the potential of the base metal and, therefore, not only isolates it from the surrounding environment, but also protects it electrochemically, succumbing to alone to corrosion, in case of leaks and the formation of electrochemical cell corrosion of the metal coating is (e.g. zinc coating on steel),
2) cathodic coating - made of metal, which within a specified corrosive environment has a higher electrochemical potential of the base metal potential, and thus protects the surface of the isolation from the surrounding environment, and in the case of leaks and the creation electrochemical cell corrosion of the substrate is metal (e.g. nickel coating on steel).
5.1 Copper plating

The copper plating is used for protective and decorative purposes. Copper is most often used as one of the layers of the multilayer coating copper-nickel-chrome, it also has technical purposes [36-38].

Electroplated embedded copper is used in electroforming and also as a protection of certain surfaces of the steel during carburizing diffusion.

Cu coatings are porous, so they are used mostly as a sub-layer imposed on steel underneath nickel or chrome. Uses a good adhesion of the coating Cu, which is of decisive importance for the quality of decorative coatings. The thickness of the coatings Cu chosen depending on the destination. The protective-decorative coatings type Cu-Ni-Cr sub-layer thickness of Cu is about 0.01 – 0.025 mm.

For copper plating there are two basic types of baths - alkaline and acidic. Among the alkaline baths there are usually cyanide baths or pyro-phosphatizing which are used.

It also applies to copper plating baths with gloss, containing the same components as bath fast efficient, but often in a different ratio with various kinds of additives brightening and wetting substances [39].

Among the copper plating bath of acid found in practical use, only the sulphate baths, and (to a lesser extent) baths fluoroborates [40].

5.2 Nickel plating

Nickel coatings should apply not only as a protective coating against corrosion and as a decorative coating, but also as a hardening coating for soft metals and alloys. They are used in the industries: automotive, sanitary and surgical, optical, food, printing, home use products, and fancy goods-decorative. Nickel coating for iron is a cathodic coating and rather mechanically protect, i.e., that the coating does not contain pores. On a steel substrate, a nickel layer underneath is often applied to the copper layer.

To achieve the lowest porosity, apply nickel layers to thickness, of about 20-30μm, which significantly increases the cost of the coating.

Nickel can also absorb relatively large quantities of hydrogen, which is often the reason for the quality of the coating being poor [41].

5.3 Chrome plating

Chrome plating is the most well-known and universally used process for applying a protective coating for the electrolytic method. Chromium plating process is the technically difficult and quite energy intensive. It is characterized by a relatively low current capacity (efficiency).

Current capacity is determined by the percentage of the ratio of the mass of metal at the cathode separated by electrolysis, under specified conditions to the mass calculated from Faraday's first rights. Also the large so-called current density is required, the current through the electrolyte per unit area of the cathode.

The chromium plating is also characterized by a low throwing power of electrolyte - the plating bath. Throwing power bath has a tendency towards the formation of a uniform plating layer on the cathode surface. Despite these unfavourable parameters chromium plating is widely used because of the performance on your valuable chromium coatings. Chrome plating is a plating baths lined with rubber or chemical-resistant Winidur - hard polyvinyl chloride, supplied with DC current from the rectifier or DC generator.

For chrome plating baths based on chromium compounds on the sixth degree of oxidation - chromic acid (VI) - are extremely dangerous to the health of humans, animals and the environment. For this reason, they are provided over the years for the intensive work on the replacement of chromium plating in the process of chromium (VI) compounds of chromium on the third degree of oxidation.

Work from this scope, conducted in Poland led to the development bath containing chromium chloride (III).
The bath is a patented; is it a good quality chromium coating with a thickness of up to 2 µm [42]. This chrome coating thickness is sufficient for decorative coatings.

Chromium iron alloys depending on the construction coatings and their production technologies can be classified into decorative and technical. Decorative chromium coating is applied to the sub-layers of copper and nickel or nickel. The role of the outer layer of chromium thickness 0.3 – 5.0 microns consists only to protect the surface from scratches and fogging. The requirements as to the quality of coatings are specified in PN-EN ISO 1456:2009.

Decorative coatings for Cu and Ni the sub-layer is commonly used in the manufacture of components for cars, motorcycles, bicycles, wagons and trams, sanitary fittings, furniture and a construction of fittings, precision instruments and other decorative elements that need to have a finished look, be resistant to abrasion and corrosion [43-48].
The purpose of this scientific paper is to analyse the surface layer steel DC01 depending on the corrosion resistance and adhesion of metal coatings on medical equipment. The assumption is looking at the choice of metallic coating, which when used for the best medical equipment will protect them from corrosion.

To assess the preparation of galvanic coatings type nickel-chromium, nickel-nickel-chromium, nickel-copper and copper without a sub-layer being imposed electrolytically, will determine the nature of the changes in the corrosion and structural steel DC01 used as a construction material in the production of medical equipment.

For testing corrosion resistance corrosive fluids are selected: Ringer's solution, artificial blood (SBF) and a solution of artificial saliva. These are the solutions, which are most commonly encountered when in contact with the protective coatings medical equipment such as operating tables, surgical, rehabilitation beds and bedside cabinets.

A methodology - the work plan of the doctoral dissertation:

- analysis of a research object,
- predict the research material,
- preparation of test samples (grinding, polishing) and the method of marking,
- assessment the geometric structure of the surface before applying galvanic coatings,
- electroplating imposition of metallic coatings (Ni, Cr, Cu) in the research material,
- an assessment of the surface layer of metallic coatings,
- metallographic research,
- X-ray microanalysis,
- research potentiodynamic corrosion resistance of metallic coatings.
RESEARCH METHODOLOGY

Research object analysis
- the topography of the surface layer in terms of three-dimensional objects
- the quantitative and qualitative analysis of the chemical composition of DC01 steel was carried according to PN-EN 10130:2009
- measurement of hardness using a universal hardness meter Zwick / Roell ZHU-250 according to PN-EN ISO 6507-1:2007
- the microstructure of steel DC01 – part of the ear of the railing Fig. 24 rehabilitation bed
- a microscopic measurement of coating thickness
- X-ray microanalysis steel element ear cut of a side railing electron microprobe model JEOL JXA-733
- bacterial tests on the corroded construction element of rehabilitation beds

Experimental materials
- steel DC01 cold rolled in the form steel sheet size 1000mm x 2000 mm and a thickness of 3mm - the construction elements of medical equipment,
- stainless RS37-2 NBK profile Ø28x2,5x1800 mm tube (welded, cold-drawn) - the construction elements of medical equipment

Types of experimental coating systems
- nickel-nickel-chromium - Fe/Ni20d/Cr - electrolytical metallic coatings, nickel coating double layer called duplex, mostly metallic coating used to protect medical equipment
- nickel-chromium - Fe/Ni10b/Cr - electrolytic metallic coatings, single-layer coating of nickel
- nickel-copper - Fe/Ni3s/Cub - electrolytic metallic coatings, semi-gloss nickel-layer coating, gloss copper
- copper - Fe/Cus - electrolytic metallic coatings, copper matte without sub-layer

Application of coating systems
- electrochemical metallic coatings using a standard electroplating bath

Tests on experimental substrate materials
- research and analysis of the chemical composition of the material to predict quantitative and qualitative for steel DC01 and RS37-2 NBK according to PN-EN 10130:2009
- measurement of the substrate hardness of the steel according to PN-EN ISO 6507-1:2007
- microscopic analysis of the structure of steel samples on the disk and the tube profile according to PN-EN ISO 643:2005
- 3D geometric structure - steel substrate according to PN-EN ISO 4287:1999 and BS EN ISO 13565-2:1999
- X-ray microanalysis point of the chemical composition of the steel substrate

Testing of the metallic coatings
- electrochemically applying metallic coatings according to the guidelines of the PN-EN ISO 1456:2009 and BS EN 1403:2002
- roughness of the surface layer of the metallic coatings according to PN-EN ISO 4287:1999 and PN-EN ISO 13565-2:1999
- measurement thickness coatings and adhesion to the metallic substrate
- X-ray microanalysis point of the chemical composition of the coatings by electron microprobe JEOL model JXA-733
- potentiodynamic testing the corrosion resistance of metallic coatings in body fluids
8.1 Research object analysis

The object of the conducted research was a rehabilitation bed side rail which had visible corrosion, subjected to systematic disinfection in a disinfection chamber to maintain the sterility of medical devices (Fig. 7a, b, c). Locus, the area subjected to corrosion is difficult to access - the inner part of the ear side rails (Fig. 7b).

The selected object study stages are presented below:

![Diagram]

Figure 7c the detailed research object was the ear, the side rails PB-02.1/N-359/00 - year 2000.

Fig. 7 a) Rehabilitation bed, equipped with side rails PB-02.1/N-359/00 - year 2000, b) place of the corrosion, c) a side rails data plate symbol LR-01.1/N-374/00 [own investigations]
Technological documentation of the side rails marked as PB-02.1/N-359/00 includes information that to ear production construction material - stainless steel cold-rolled DC01w was used with a 3mm thickness and the information about the technology course of the ear preparation for galvanic treatment.

Topography measurements were made on the surface layer, cut out from the part of the side rails ear without any visible corrosion (Fig. 8a). A three-dimensional graphical image with measurement results is presented at Fig. 8b.

![Fig. 8](image)

**Fig. 8** a) the part cut out of a side rail with no corrosion traces PB-02.1/N-359/00, b) the topography of the surface layer in terms of three-dimensional [own investigations]

The quantitative and qualitative analysis of the chemical composition of DC01 steel was carried according to PN-EN 10130:2009 the standard emission spectrometer with an inductively coupled plasma ICP-OES. Whereas, carbon and sulfur were determined with a carbon and sulfur analyzer LECO CS-125. The results are presented in Table 5.

Table 1. The steels for testing according to EN 10130:2009 and the results of chemical analysis

<table>
<thead>
<tr>
<th>Results source</th>
<th>DC01 chemical analysis in [%] by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>According to PN-EN 10130:2009</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>≤ 0,120</td>
</tr>
<tr>
<td>According to chemical analysis</td>
<td>0,082</td>
</tr>
</tbody>
</table>

A hardness measurement was performed using a universal hardness tester Zwick / Roell ZHU-250, PN-EN ISO 6507-1:2007. The average hardness was 106 HV1.

A microscopic analysis of the element cut from the ear at a magnification of 100, 500 and 1000x indicates that the steel structure is composed of fine grain typical of cold-rolled products (Fig. 9).

![Fig. 9](image)

**Fig. 9** The microstructure of steel DC01 – a fragment of the ear of the railing, a) magnification 100x, b) magnification e 500x, c) magnification 1000x
A microscopic measurement of coating thickness were performed using a microscope metallographic Carl Zeiss AxioImager.M1m at a magnification of 500 and 1000x.

An x-ray microanalysis of the ear element cut from the side railing steel was made by an electron microprobe JEOL model JXA-733 application.

The sample cross sections with protective coating with corrosion (Fig.10) and without corrosion (Fig.11) were analyzed metallographically.

The analysis was conducted at an accelerating voltage of 15kV. The analysis results of the examined metallographic specimens cross sections are presented in Table 2.

![Fig.10 An x-ray microanalysis on the cross section](image)

<table>
<thead>
<tr>
<th>Analyzed element</th>
<th>Place analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Fe</td>
<td>98,90</td>
</tr>
<tr>
<td>Ni</td>
<td>0,19</td>
</tr>
<tr>
<td>Cr</td>
<td>0,00</td>
</tr>
</tbody>
</table>

Table 2 The results of the chemical microanalysis to cross the boundary layers of nickel-nickel-chromium of the background and of the material (ear cutting from a side rails without corrosion)

![Fig.11 An x-ray microanalysis point corrosion products](image)

The graphs X-ray energy spectra of the sample with corrosion - EDS (Energy Dispersive Spectroscopy) – Fig. 12.
8.2 **Bacteria identification at corroded construction's elements surface**

For testing, the medical equipment - rehabilitation bed marked as LP-01.0 (production year - 1994) was chosen, where the local corrosion was observed. Next, two elements with visible corrosion were cut from the steel construction of the bed (Fig. 13). This material with galvanic coating type nickel-nickel-chromium was subjected to microbiological examinations in order to establish the bacteria kind settling in niches, cavities and on a protective layer of examined elements.

Samples were incubated in 37 °C in 50 BHI ml. Every hour bacterial culture was mixed within 5 min, and the surface inoculation was being carried out on BHI agar: after the first hour 0,5 ml, in next following hours 0,1 ml. After 24 hours of incubation the bacterial cultures were identified and counted. After 24 hours of cultivation 0,1ml of every fluid culture in dilution 10^{-4} and 10^{-6} was surface inoculated on a chosen basis. The final bacteria identification of the biochemical API tests were made.

At the first sample (Fig. 13 b) Bacillus cereus strain was identified, whereas on the second (Fig. 14 c) Staphylococcus aureus and Acinetobacter baumannii were identified.
8.3 Material for research

For testing the chosen construction material - in the form of steel DC01 cold rolled steel sheet size 1000mm x 2000 mm and a thickness of 3mm (Fig. 14 a, b) and stainless RSt37-2 NBK profile Ø28x2,5x1800 mm tube (welded, cold-drawn) (Fig. 15) for the construction elements of medical equipment.

With randomly selected areas of cut sheet sample (with a diameter of 14.6 mm and technological hole Ø1,5 mm at a distance of 1 mm from the lateral edge of the disc – Fig.14b) Laser BY-STRONIC - model Byspeed 3015.

However from the pipe there were samples prepared for 50 mm lengths with the technological hole technology at Ø3,5 mm, 5 mm distance from the side edge (Fig. 15b).
THE CHEMICAL COMPOSITION OF THE BASE MATERIAL

The quantitative and qualitative analysis of the chemical composition of DC01 and steel was carried out according to PN-EN 10130:2009 a standard emission spectrometer with inductively coupled plasma ICP-OES. Whereas, carbon and sulfur were determined on the carbon and sulfur analyzer LECO CS-125. The results are presented in Table 3.

<table>
<thead>
<tr>
<th>Results source</th>
<th>The chemical composition of steel DC01 in [%] by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>According to PN-EN 10130:2009</td>
<td>≤ 0,120</td>
</tr>
<tr>
<td>According to chemical analysis</td>
<td>0,070</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Results source</th>
<th>The chemical composition of steel RSt37-2 NBK in [%] by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>According to PN-EN 10130:2009</td>
<td>0,09~0,15</td>
</tr>
<tr>
<td>According to chemical analysis</td>
<td>0,14</td>
</tr>
</tbody>
</table>
8.4 Preparation of samples for research

Samples of steel in the form of discs (Fig. 14), mechanically ground abrasive disks with granulation 80 and 120 with a grinding paste of ABRA applied then polished. However, the geometry of the sample tube on the ground abrasive disks with granulation 240, 400, 600, 800 without polishing (Fig. 15).

The sample preparation was compatible with the technology to prepare the construction elements for the galvanic machining in the production of medical equipment.

8.5 An assessment of the geometric structure surface of samples before and after the application of metallic coatings

The study of the surface layer of the disc profile samples (Ø14, 6 mm) and samples from the pipe Ø28x2,5x50 mm before (after grinding and polishing), and after putting galvanic coatings was performed by using a contact classical profilometer Perthometer Concept Mahr with table Y-drive PKT.

The results will be presented in the form of a three-dimensional image - 3D was achieved using software PERTHOMETER CONCEPT v.6.50.

The results in the form of the three dimensional image - 3D and a curved share of the material in graphic form (Fig. 16, 17) was obtained using the software PERTHOMETER CONCEPT v.6.50.

Additionally to the quantitative description of surface roughness, chosen in accordance with PN-EN ISO 4287:1999 and PN-EN ISO 13565-2:1999 (defined parameters determined on the basis of the participation of material curve linearization), geometrical parameters: $Ra$ - arithmetical mean deviation of the roughness profile, $Mr1$ - material participation (in percent) determined by the intersection of the line separating the hills protruding from the roughness core profile and $Mr2$ - material participation (in percentage) determined by the intersection of the line separating the deep recesses of the roughness core profile.

The core profile roughness means the roughness profile without distinctive hills and deep valleys.

**AN ASSESSMENT OF THE SURFACE LAYER OF THE DISC GEOMETRY SAMPLES WITHOUT GALVANIC COATING**

![Fig.16](image)

*Fig.16  A profile of a sample of the disc geometry, a) the topography of the surface layer - 3D, b) curve share of the material of the sample geometry of the disc without the coating (after the process of grinding and polishing)*
AN ASSESSMENT OF THE SURFACE LAYER OF THE PIPE GEOMETRY SAMPLES WITHOUT GALVANIC COATING

Fig.17  A profile of a sample of the pipe geometry, a) the surface layer topography - 3D, b) curve share sample material with a geometry pipe without coating (after grinding process)

8.6 Electrolytic metal coatings – Ni, Cr, Cu

An electrolytic coating was imposed according to the requirements of the standard PN-EN ISO 1456:2009 and PN-EN 1403: 2002 conventional galvanic baths as the corrosion protection of steel in the production of medical equipment.

Galvanic layers were applied to a steel substrate of the disc and a tube geometry (Fig.18) in the combinations shown in Table 4.

Table 4  Combinations of galvanic coatings for the disc and tube profile

<table>
<thead>
<tr>
<th>Description of coatings</th>
<th>Designation for disc</th>
<th>Designation for pipe according to PN-EN ISO 1456:2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>nickel-nickel-chromium</td>
<td>Fe/Ni20d/Cr</td>
<td>Fe/Ni20d/Cr</td>
</tr>
<tr>
<td>nickel-chromium</td>
<td>Fe/Ni10b/Crr</td>
<td>Fe/Ni10b/Crr</td>
</tr>
<tr>
<td>nickel-copper</td>
<td>Fe/Ni3s/Cub</td>
<td>Fe/Ni3s/Cub</td>
</tr>
<tr>
<td>copper</td>
<td>Fe/Cus</td>
<td>Fe/Cus</td>
</tr>
</tbody>
</table>

Where: Fe – mean substrate, Ni - nickel coating, 20 - minimum thickness of nickel coating (20 μm), d – nickel coating double layer called duplex, b – nickel coating single-layer with a minimum thickness 10 μm, Crr – standard chrome coating with a minimum thickness of 0.3 μm, 3 – nickel coating thickness (3 μm), s – semi gloss nickel-layer coating, Cub – gloss copper, Cus – matte copper.

Plating a nickel-copper does not have its counterpart in the Polish standards.

Before the imposition multilayer coatings of metal samples were divided into 4 groups according to the determinations provided below:

- for samples with geometry of the disc:
  0 - samples without coating
  A - sample with coating nickel-nickel-chromium (Fe/Ni20d/Crr)
  B - samples with coating nickel-chromium (Fe/Ni10b/Crr)
  C - samples with coating nickel-copper (Fe/Ni3s/Cub)
  D – samples with coating copper (Fe/Cus)
The research material on disk geometry and pipes after the application of galvanic coatings divided into groups - a general view

<table>
<thead>
<tr>
<th>Gr. A</th>
<th>Gr. B</th>
<th>Gr. C</th>
<th>Gr. D</th>
</tr>
</thead>
<tbody>
<tr>
<td>nickel-nickel-chrome</td>
<td>nickel-nickel-chrome</td>
<td>nickel-cooper</td>
<td>cooper (without sublayer)</td>
</tr>
<tr>
<td>Fe/Ni20d/Crr</td>
<td>Fe/Ni10b/Crr</td>
<td>Fe/Ni3s/Cub</td>
<td>Fe/Cus</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gr. I</th>
<th>Gr. II</th>
<th>Gr. III</th>
<th>Gr. IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>nickel-nickel-chrome</td>
<td>nickel-nickel-chrome</td>
<td>nickel-cooper</td>
<td>cooper (without sublayer)</td>
</tr>
<tr>
<td>Fe/Ni4d/Crr</td>
<td>Fe/Ni4d/Crr</td>
<td>Fe/Ni3s/Cub</td>
<td>Fe/Cus</td>
</tr>
</tbody>
</table>

**Fig. 18**

*NICKEL COATING APPLICATION PROCESS*

The imposition of electrolytic nickel coatings bath used Omega-Super (nickel semi-gloss) and SUPRAGAL 2000G (nickel gloss) developed by Dr. HESSE & CIE.

The coatings applied to steel samples subjected to undergoing a prior treatment of mechanical and chemical preparation. Samples were suspended for technological hole copper wire ø0.5 mm the copper hooks affixed to a copper cathode.

The coatings were applied in two combinations as triple - this applies to samples from group A and I and two-layer samples for group B and II (Fig. 18).

Three-layer coating contains nickel semi-gloss (bath Omega-Super) glossy nickel (bath SUPRAGAL 2000G) and decorative chrome baths DC-700. The coating double layer consists of nickel glossy (bath SUPRAGAL 2000G) and decorative chromium (bath DC-700).

**A DECORATIVE CHROME SAMPLE PROCESS OF STEEL GROUP A, B and I, II**

A decorative chrome plating process was carried out in a chromic acid based bath, enriched with additives improving the ability of coverage and a speed of applying a coating.

**PROCESS COPPER PLATING**

Copper plating was carried out in two groups of samples C, D, and group III and IV. Group C and III were treated by applying a coating of copper plating with a high gloss (shiny) on the sub-layer of nickel. For sample D, and IV the group also applied by electrolysis method copper coating matte directly to the substrate, using alkaline solutions based on cyanides.
COATING - COPPER HIGH GLOSS

The imposition of high gloss copper was used in the RUBIN WK bath, whereas the bath for the nickel plating semi-gloss (nickel base) is a PRE-SIRIUS. Both baths are made with Metallchemie Chemische Fabrik.

COPPER COATING - MATT

The process of copper plating in an alkaline cyanide bath of steel samples of group D and IV was made by electrolysis.

8.7 Evaluation of the surface layer of metallic coatings imposed

The study of the geometrical structure of the surface layer of the electroplated coatings imposed on the sample profile of the disc (Ø14,6 mm) and the pipe (Ø28x2, 5x50 mm), was performed by using a contact profilometer Perthometer Concept Mahr with table Y-drive PKT.

The results of measurements in 3D and curves in participation of material in graphic form (Figure 19-26) was determined using the software Perthometer CONCEPT v.6.50, as mentioned earlier on page 24.

AN EVALUATION OF THE SURFACE LAYER NICKEL-NICKEL-CHROME COATING ON A SAMPLE OF A GEOMETRY DISC

![Fig.19](image1.png)

A sample the geometry of the disc with nickel -nickel-chromium coating, a) topography of the surface layer in terms of 3D, b) the curve participation of material

AN EVALUATION OF THE SURFACE LAYER NICKEL-CHROME COATING ON A SAMPLE OF GEOMETRY DISC

![Fig.20](image2.png)

A sample of a geometry disk with a nickel-chrome coating, a) topography of the surface layer in terms of 3D, b) the curve participation of material
AN EVALUATION OF THE SURFACE LAYER NICKEL-COPPER COATING ON A SAMPLE OF A GEOMETRY DISC

Fig. 21  A sample of a geometry disk with a nickel-copper coating, a) topography of the surface layer in terms of 3D, b) the curve of participation of the material

AN EVALUATION OF THE SURFACE LAYER COPPER COATING ON A SAMPLE OF A GEOMETRY DISC

Fig. 22  A sample of a geometry disk with a copper coating, a) topography of the surface layer in terms of 3D, b) the curve of participation of the material

AN EVALUATION OF THE SURFACE LAYER NICKEL-NICKEL-CHROME COATING ON A SAMPLE OF THE GEOMETRY PIPE

Fig. 23  A sample of a geometry pipe with a nickel-nickel-chrome coating, a) topography of the surface layer in terms of 3D, b) the curve of participation of the material
AN EVALUATION OF THE SURFACE LAYER NICKEL-CHROME COATING ON A SAMPLE OF GEOMETRY PIPE

Fig. 24 A sample geometry pipe with a nickel-chrome coating, a) topography of the surface layer in terms of 3D, b) the curve of participation of the material

AN EVALUATION OF THE SURFACE LAYER NICKEL-COPPER COATING ON A SAMPLE OF GEOMETRY PIPE

Fig. 25 A sample of the geometry pipe with a nickel-copper coating, a) topography of the surface layer in terms of 3D, b) the curve of participation of the material

AN EVALUATION OF THE SURFACE LAYER OF THE COPPER COATING ON A SAMPLE OF GEOMETRY PIPE

Fig. 26 A sample of the geometry pipe with a copper coating, a) topography of the surface layer in terms of 3D, b) the curve of participation of the material
8.8 Metallographic tests

Metallographic tests will be performed on samples of steel in the form of discs of Ø14.6 mm (Fig. 14, page 22) - DC01 steel and tube samples Ø28x2.5x50 mm - stainless RSt37 NBK-2 (Fig. 15, page 23), with superimposed metallic coatings.

Prepared metallographic specimen was to observation the macro, microscopic and X-ray microanalysis. Directly before the metallographic testing surface layer were etch nital (3% solution of nitric acid in ethanol).

Microscopic analyses of the steel structure for samples of the disc and pipes profile were made according to standard PN-EN ISO 643:2005 on metallographic microscope Carl Zeiss Axiomager. M1m at a magnification of 100, 500 and 1000x.

**MICROSCOPIC METALLOGRAPHY SAMPLES OF GEOMETRY DISC**

Microscopic analysis of steel at a magnification of 100, 500 and 1000x for samples of the geometry disk shows the structure of ferrite grain fine and evenly distributed. Cementite spherical separation was also observed uniformly distributed inside the grains and insignificant quantities plate cementite at the grain boundary (Fig. 27).

The structure of a typical cold-rolled low-carbon steel, alloy steels for cold forming (e.g., bending, stamping).

**Fig. 27** A microstructure of DC01 steel – a disk profile was digested nital a) 100x magnification, b) 500x magnification, c) 1000x magnification [own investigations]

**MICROSCOPIC METALLOGRAPHY SAMPLE OF THE PIPE GEOMETRY**

A microscopic analysis of steel at a magnification of 100x, 500x and 1000x for the sample pipe geometry shows the structure of ferrite grain fine evenly distributed. The spin cementite ball evenly distributed the grains inside and insignificant quantities cementite plate at the grain boundary (Fig. 28).

The structure is similar to flat samples.

**Fig. 28** A microstructure of steel RSt37-2 NBK – a profile pipe was digested nital, a) 100x magnification, b) 500x magnification, c) 1000x magnification [own investigations]
METALLIC COATING MEASUREMENT THICKNESS

Measuring the thickness of galvanic coatings produced (Table 5 and 6), and their adhesion to the metal substrate for the profile disk and pipe was analyzed using metallographic microscope Carl Zeiss AxioImager.M1m at a magnification of 500 and 1000X (Fig. 29-32).

A MEASUREMENT THICKNESS COATINGS AND ADHESION TO THE METALLIC SUBSTRATE FOR THE PROFILE DISC

Fig. 29
A microscopic measurement thickness coatings and adhesion to the metallic substrate, a) nickel-nickel-chrome (Fe//Ni20dCrr), b) nickel-chrome (Fe//Ni10bCrr) – profile disc

Fig. 30
A microscopic measurement thickness coatings and adhesion to the metallic substrate, a) nickel-copper (Fe//Ni3sCu), b) copper Fe//Cup) – profile disc

A MEASUREMENT OF THE THICKNESS OF THE COATINGS AND THE ADHESION TO THE METALLIC SUBSTRATE FOR THE PROFILE PIPE

Fig. 31
A microscopic measurement thickness coatings and adhesion to the metallic substrate, a) nickel-nickel-chrome (Fe//Ni48dCrr), b) nickel-chrome (Fe//Ni40bCrr) – profile pipe

Fig. 32
A microscopic measurement thickness coatings and adhesion to the metallic substrate, a) nickel-copper (Fe//Ni5xCub), b) copper (Fe//Cup) – and profile pipe
Table 5  The results of the measurement thickness galvanic layer for samples profile disk and pipe

<table>
<thead>
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<td></td>
<td></td>
</tr>
<tr>
<td>Profile disc</td>
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</tr>
<tr>
<td>11</td>
<td>nickel-nickel</td>
<td>23,4 23,7 23,6</td>
<td>23,7 23,4 23,6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>chrome</td>
<td>0,4 0,4 0,4</td>
<td>0,4 0,4 0,4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>21</td>
<td>nickel</td>
<td>13,0 13,2 13,2</td>
<td>13,2 13,0 13,1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>chrome</td>
<td>0,4 0,4 0,4</td>
<td>0,4 0,4 0,4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>31</td>
<td>nickel</td>
<td>3,4 3,3 3,3</td>
<td>3,4 3,3 3,3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>copper</td>
<td>10,0 10,6 10,1</td>
<td>10,6 10,0 10,2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>710</td>
<td>copper</td>
<td>30,0 30,0 29,0</td>
<td>29,0 29,0 29,7</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Profile pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R12</td>
<td>nickel</td>
<td>37,0 37,0 37,0</td>
<td>37,0 37,0 37,0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>chrome</td>
<td>1,0 1,0 1,0</td>
<td>1,0 1,0 1,0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R21</td>
<td>nickel</td>
<td>42,0 41,1 42,0</td>
<td>42,0 41,0 41,7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>chrome</td>
<td>1,0 1,0 1,0</td>
<td>1,0 1,0 1,0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R32</td>
<td>nickel</td>
<td>5,0 5,0 5,0</td>
<td>5,0 5,0 5,0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>copper</td>
<td>12,0 12,0 12,0</td>
<td>12,0 12,0 12,0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R74</td>
<td>copper</td>
<td>25,0 25,0 24,0</td>
<td>24,0 24,0 24,7</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 6  Average values of coating thickness for different combinations

<table>
<thead>
<tr>
<th>Combination of coatings</th>
<th>Average thickness of the coatings -profile disc [µm]</th>
<th>Average thickness of the coatings - profile pipe [µm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>nickel-nickel-chrome</td>
<td>24,0</td>
<td>49,0</td>
</tr>
<tr>
<td>nickel-chrome</td>
<td>13,5</td>
<td>42,7</td>
</tr>
<tr>
<td>nickel-copper</td>
<td>13,5</td>
<td>17,0</td>
</tr>
<tr>
<td>copper</td>
<td>29,7</td>
<td>24,7</td>
</tr>
</tbody>
</table>

**A SUBSTRATE HARDNESS MEASUREMENT**

A hardness of the steel substrate samples of the disc and tube geometry was performed by classical on a universal hardness tester Zwick / Roell ZHU-250, PN-EN ISO 6507-1:2007. Was used with a load equal to HV 1. HV 1 means that the test was conducted at a load of 1 kgf, (1kgf - one kilogram-force, 1kgf = 9,80665 N).

The results of the hardness measurement are shown in Table 7 and Figure 33.
Table 7  Results of the hardness measurement of the substrate samples geometry of the disc and pipe

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel DC01 (disk geometry)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>109</td>
<td>111</td>
<td>106</td>
<td>113</td>
<td>111</td>
</tr>
<tr>
<td>12</td>
<td>103</td>
<td>107</td>
<td>105</td>
<td>103</td>
<td>105</td>
</tr>
<tr>
<td>21</td>
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<td>107</td>
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<td>102</td>
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<tr>
<td>22</td>
<td>103</td>
<td>105</td>
<td>107</td>
<td>110</td>
<td>114</td>
</tr>
<tr>
<td>31</td>
<td>105</td>
<td>101</td>
<td>102</td>
<td>104</td>
<td>105</td>
</tr>
<tr>
<td>32</td>
<td>106</td>
<td>106</td>
<td>102</td>
<td>103</td>
<td>107</td>
</tr>
<tr>
<td>Steel RSt37-2 NBK (pipe geometry)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R01</td>
<td>137</td>
<td>137</td>
<td>143</td>
<td>145</td>
<td>145</td>
</tr>
<tr>
<td>R12</td>
<td>139</td>
<td>139</td>
<td>140</td>
<td>139</td>
<td>141</td>
</tr>
<tr>
<td>R21</td>
<td>138</td>
<td>139</td>
<td>143</td>
<td>145</td>
<td>142</td>
</tr>
<tr>
<td>R32</td>
<td>137</td>
<td>142</td>
<td>141</td>
<td>144</td>
<td>144</td>
</tr>
<tr>
<td>R74</td>
<td>141</td>
<td>137</td>
<td>138</td>
<td>141</td>
<td>141</td>
</tr>
<tr>
<td>R75</td>
<td>141</td>
<td>144</td>
<td>140</td>
<td>138</td>
<td>138</td>
</tr>
</tbody>
</table>

Fig. 33  Hardness measurements taking into account the standard deviation
8.9 X-ray microanalysis

An x-ray microanalysis point of the chemical composition of the substrate and coating was made by an electron microprobe JEOL model JXA-733.

Metallographic specimen were subjected to analysis cross the sections of the geometry of the disc - DC01 steel, with multi-layered metallic coatings.

The analysis was conducted at an 15 kV accelerating voltage. The results are presented graphically in the form of graphs, X-ray energy spectrum - EDS (Energy dispersive spectroscopy).

The results of the observation and analysis of the test micro-areas of the selected samples in the drawings from 34 to 43 and tables 8 to 11.

AN X-RAY MICROANALYSIS SAMPLE WITH NICKEL- NICKEL-CHROME COATING
(Fe//Ni20dCr)

![Image of X-ray microanalysis sample with nickel-nickel-chrome coating](image)

**Fig. 34** X-ray microanalysis steel points - point 5,6 and nickel coating I - point 3,4 and nickel II - point 1,2 - 5000x magnification and point + Cr. 10000x magnification

<table>
<thead>
<tr>
<th>Analyzed element</th>
<th>Place of analysis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>+Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Content in [%] by weight.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td></td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>1,91</td>
<td>100,00</td>
<td>100,00</td>
<td>0,00</td>
</tr>
<tr>
<td>Ni</td>
<td></td>
<td>100,00</td>
<td>100,00</td>
<td>100,00</td>
<td>98,09</td>
<td>0,00</td>
<td>0,00</td>
<td>9,83</td>
</tr>
<tr>
<td>Cr</td>
<td></td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>90,17</td>
</tr>
</tbody>
</table>
AN X-RAY MICROANALYSIS SAMPLE WITH NICKEL-CHROME COATING
(Fe//Ni10bCr)

Fig. 35 An x-ray energy spectrum obtained from the layer of nickel II, a) point 1, b) point 2

Fig. 36 An x-ray energy spectrum obtained from the layer of nickel I, a) point 3, b) point 4

Fig. 37 An x-ray energy spectrum obtained from the steel substrate - point 5

Fig. 38 X-ray microanalysis steel points - point 3, 4 and nickel coating - point 1, 2 and point + Cr. 10000x magnification
Table 9  Chemical microanalysis results for a cross section on the border layers of nickel-chrome (Fe//Ni10bCr)

<table>
<thead>
<tr>
<th>Analyzed element</th>
<th>Place of analysis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>+Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Content in [%] by weight.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td></td>
<td>1,25</td>
<td>2,37</td>
<td>97,31</td>
<td>100,00</td>
<td>0,00</td>
</tr>
<tr>
<td>Ni</td>
<td></td>
<td>98,75</td>
<td>97,63</td>
<td>2,69</td>
<td>0,00</td>
<td>81,86</td>
</tr>
<tr>
<td>Cr</td>
<td></td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>5,92</td>
</tr>
<tr>
<td>Ca</td>
<td></td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>3,18</td>
</tr>
<tr>
<td>Al</td>
<td></td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>4,30</td>
</tr>
<tr>
<td>Si</td>
<td></td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>4,74</td>
</tr>
</tbody>
</table>

Fig.39  An x-ray energy spectrum obtained from the nickel layer, a) point 1, b) point 2

Fig.40  An x-ray energy spectrum obtained from the steel substrate, a) point 3, b) point 4

Fig.41  An x-ray energy spectrum obtained from the chromium layer - point +Cr

37
AN X-RAY MICROANALYSIS SAMPLE WITH NICKEL-COPPER COATING (Fe//Ni5sCub)

Fig. 42 X-ray microanalysis steel points - point 5,6 and nickel coating - point 3,4 and copper coating - point 1,2. 8000x magnification

Table 10 Chemical microanalysis results for a cross section on the border layers of nickel-copper (Fe//Ni5sCub)

<table>
<thead>
<tr>
<th>Analyzed element</th>
<th>Place of analysis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td></td>
<td>0,00</td>
<td>0,00</td>
<td>2,41</td>
<td>3,01</td>
<td>98,77</td>
<td>100,00</td>
<td>-</td>
</tr>
<tr>
<td>Ni</td>
<td></td>
<td>0,00</td>
<td>0,00</td>
<td>90,27</td>
<td>96,99</td>
<td>1,23</td>
<td>0,00</td>
<td>-</td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td>100,00</td>
<td>100,00</td>
<td>6,48</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>-</td>
</tr>
<tr>
<td>Mo</td>
<td></td>
<td>0,00</td>
<td>0,00</td>
<td>0,97</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
<td>-</td>
</tr>
</tbody>
</table>

AN X-RAY MICROANALYSIS SAMPLE WITH A COPPER COATING (Fe//Cup)

Fig. 43 An x-ray microanalysis steel points - point 3,4 and copper coating - point 1,2. 4000x magnification

38
Table 11  Chemical microanalysis results for a cross section on the border layer copper coating (without sub-layer) - steel substrate (Fe/Cu)

<table>
<thead>
<tr>
<th>Analyzed element</th>
<th>Place of analysis</th>
<th>Content in [%] by weight.</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fe</td>
<td>0,00</td>
<td>1,11</td>
</tr>
<tr>
<td>Cu</td>
<td>100,00</td>
<td>98,89</td>
</tr>
</tbody>
</table>

8.10 Potentiodynamic corrosion tests

Samples of corrosion resistance with a created metallic coatings were determined using potentiodynamic tests that results in the form of curves of the polarization. It was used in an automated measuring system which comprises of: measuring vessel, potentiostat SI 1286 and a computer.

Polarization curves were recorded in the conventional system of three electrodes. Before starting the measurement, the samples were placed in a corrosive solution (body fluids), in a solution of artificial saliva, artificial blood (SBF-Simulated Body Fluid) and Ringer's solution at 20 °C for 24 hours. The chemical composition is presented in Table 12. Next they were subjected to the polarization of the potential -1000 mV\(_{NEK}\) in the anode direction at a rate of 1 mV/s.

The following notation: \(E_{\text{kor}}\) - corrosion potential (stationary) samples after 24-hours of exposure to a corrosive solution, \(i_{\text{kor}}\) - cathodic current density at a potential -750 mV, \(E_{\text{KA}}\) - transition potential cathode-anode, \(R_p\) - polarization resistance, \(i_{\text{kor}}\) - corrosion current density.

Table 12 The chemical composition and sequence of added reagents for the synthesis of body fluids: artificial saliva, artificial blood, Ringer's solution

<table>
<thead>
<tr>
<th>Component</th>
<th>Artificial saliva solution</th>
<th>SBF (solution artificial blood)</th>
<th>Ringer's solution (saline solution)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>0,700</td>
<td>7,996</td>
<td>8,600</td>
</tr>
<tr>
<td>NaHCO(_3)</td>
<td>1,500</td>
<td>0,350</td>
<td>-</td>
</tr>
<tr>
<td>KCl</td>
<td>1,200</td>
<td>0,224</td>
<td>0,300</td>
</tr>
<tr>
<td>CaCl(_2)</td>
<td>-</td>
<td>-</td>
<td>0,243</td>
</tr>
<tr>
<td>Na(_2)HPO(_4) · 2H(_2)O</td>
<td>0,326</td>
<td>0,348</td>
<td>-</td>
</tr>
<tr>
<td>MgCl(_2) · 6H(_2)O</td>
<td>-</td>
<td>0,305</td>
<td>-</td>
</tr>
<tr>
<td>1M HCl</td>
<td>-</td>
<td>47,200</td>
<td>-</td>
</tr>
<tr>
<td>CaCl(_2) · 6H(_2)O</td>
<td>-</td>
<td>0,549</td>
<td>-</td>
</tr>
<tr>
<td>Na(_2)SO(_4)</td>
<td>-</td>
<td>0,071</td>
<td>-</td>
</tr>
<tr>
<td>(CH(_2)OH(_2)CHN(_2)</td>
<td>-</td>
<td>6,057</td>
<td>-</td>
</tr>
<tr>
<td>KSCN (potassium thiocyanate)</td>
<td>0,330</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CO(NH(_2))(_2) (urea)</td>
<td>1,500</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
The results of the electrochemical research for DC01 and a multi-layer of metallic coatings electrochemically imposed is presented in the form of a cathodic and anodic polarization curves (Fig. 44 and 45). The presented results of potentiodynamic and polarization curves graphs obtained, show the differences of material properties (Table 13). Method of preparation (modification) of the surface layer of samples has an effect on the corrosion resistance of the metal layers.

Table 13  The values of corrosion currents and potentials determined for samples with metallic coatings

<table>
<thead>
<tr>
<th>Body fluid</th>
<th>Number of samples</th>
<th>$E_{\text{cor}}$ [mV]</th>
<th>$i_{E=-750}$ [A/cm²]</th>
<th>$E_{\text{K-A}}$ [mV]</th>
<th>$R_p$ [Ωcm²]</th>
<th>$i_{kor}$ [A/cm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBF (solution artificial blood)</td>
<td>17</td>
<td>-124</td>
<td>3,40 $10^{-5}$</td>
<td>-198</td>
<td>2,29 $10^5$</td>
<td>1,14 $10^5$</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>-292</td>
<td>4,76 $10^{-5}$</td>
<td>-322</td>
<td>1,64 $10^5$</td>
<td>1,58 $10^5$</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>-193</td>
<td>4,23 $10^{-5}$</td>
<td>-193</td>
<td>3,11 $10^5$</td>
<td>4,65 $10^5$</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>-196</td>
<td>2,21 $10^{-5}$</td>
<td>-230</td>
<td>0,12 $10^5$</td>
<td>2,18 $10^6$</td>
</tr>
<tr>
<td>Artificial saliva solution</td>
<td>19</td>
<td>-249</td>
<td>1,70 $10^{-5}$</td>
<td>-301</td>
<td>4,93 $10^5$</td>
<td>5,29 $10^5$</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>-103</td>
<td>2,82 $10^{-5}$</td>
<td>-173</td>
<td>3,74 $10^5$</td>
<td>6,98 $10^5$</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>-83</td>
<td>8,62 $10^{-5}$</td>
<td>-327</td>
<td>0,87 $10^5$</td>
<td>2,99 $10^5$</td>
</tr>
<tr>
<td></td>
<td>76</td>
<td>-137</td>
<td>6,03 $10^{-5}$</td>
<td>-245</td>
<td>0,84 $10^5$</td>
<td>3,09 $10^5$</td>
</tr>
<tr>
<td>Ringer’s solution (saline solution)</td>
<td>08</td>
<td>-539</td>
<td>1,07 $10^{-5}$</td>
<td>-570</td>
<td>1,55 $10^5$</td>
<td>1,68 $10^5$</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>-486</td>
<td>6,65 $10^{-5}$</td>
<td>-494</td>
<td>4,0705</td>
<td>6,41 $10^5$</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>-430</td>
<td>1,71 $10^{-5}$</td>
<td>-447</td>
<td>1,83 $10^5$</td>
<td>1,43 $10^5$</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>-253</td>
<td>2,12 $10^{-5}$</td>
<td>-250</td>
<td>2,50 $10^5$</td>
<td>1,04 $10^5$</td>
</tr>
<tr>
<td></td>
<td>710</td>
<td>-126</td>
<td>1,79 $10^{-5}$</td>
<td>-173</td>
<td>0,29 $10^5$</td>
<td>8,76 $10^7$</td>
</tr>
</tbody>
</table>

The drawings below shows the polarization curves for samples 17, 28, 37, 75 (solution artificial blood - SBF) and 19, 29, 39, 76 (solution of artificial saliva) and 08,16,27,36,710 (Ringer's solution) in different combinations coatings after 24 hours of exposure in the corrosion solution.

Fig.44  a) Polarization curves obtained for the samples of steel with metallic coatings in the corrosion centers

40
Fig. 45  
Polarization curves obtained for samples of steel with imposed metallic coatings in Ringer solution
9 A SUMMARY AND DISCUSSION OF RESULTS

In the literature dealing with the selection of material and surface preparation equipment the design elements, medical equipment dental and peripheral equipment operating rooms have not found any information relating to the sustainability of metallic coatings deposited on the base elements.

The criteria for quality medical specify individual standards based on the recommendations contained in the Act on Medical Products [Journal Polish Set 2010 nr107 pos. 679]. These standards define the structural and functional characteristics of hospital equipment and these are also issues related to applied construction materials (type and quality), and protective coatings.

- An analysis of the chemical composition of the steel DC01 (the geometry of the disc) and RSt37-2 NBK (the geometry of the pipe) (Tab. 3) for analysis confirmed the compliance with standards and specifications submitted by the supplier. The hardness tests showed little difference between the two steel grades. Was respectively DC01 106 HV1 and for RSt37-2 NBK 140 HV1.

- The adopted standard preparation of the test material is consistent with the technology which spaces design elements prepared under the galvanic treatment of the manufacturing plant of medical equipment.

- In the assessment of the surface layer of the samples before the imposition, galvanic coatings must be observed so that the geometry of the sample pipes have a higher degree of development of the surface (Ra 0,18 µm) than the samples of geometry disk (Ra of 0,10 µm).

The curve participation of the material informs that the profile surface of the disc has a larger share coefficient Mr1 (elevations protruding from the roughness core profile), which was 9,20%, compared to the pipe - Mr1 5,82%, inequality. However coefficient Mr2 (deep valley of the roughness core profile) for the profile of the pipe amounted to 92,23 %. It follows from this that the grinding with polishing the samples in the form of disc gave more (continuous) a flat surface - Mr2 87,91% (Fig. 16, 17).

- Metallographic tests thickness layers of metallic coatings for the disc showed that the average thickness of the coating nickel-nickel-chrome is 24,0 µm, nickel-chrome 13,5 µm (Fig. 29a). Fulfills the conditions of the standards relating to the requirements that apply to the hospital conditions. A coating thickness for samples with a pipe geometry amounted for the coatings: nickel-nickel-chrome 49,0 µm, nickel-chrome 42,7 µm, nickel-copper 17,0 µm and copper 24,7 µm (Fig. 31, 32). This case in the assessment of the surface layer before and after the imposition of galvanic coatings shows a slightly adjusted surface profile (raw - Ra 0,18 µm, nickel-nickel-chrome coating - Ra 0,4 µm, nickel-chrome coating - Ra 0,17 µm).

The resulting coatings nickel-nickel-chromium and nickel-chrome is a significant thickness in relation to the geometry of the disc sample was intended in-order to demonstrate an absence of difference in the adhesion to the steel substrate.

- The research stereo-meteric disc geometry samples performed after the imposition of the metallic coatings indicate that the surface layer has been development in relation to the samples in the initial state (Ra 0,10 µm, Fig. 16a). Copper coating (without sublayer) with Ra 0,24 µm has the largest roughness coefficient (Fig. 22a). For other samples with coatings nickel-nickel-chrome (Ra 0,14 µm), nickel-chrome (Ra 0,11 µm), nickel-copper (Ra 0,12 µm) there has been a slight increase in the average roughness factor 0,02 µm (Fig. 19a, 20a 21a).

The surface layer samples profile the pipe with coatings nickel-nickel-chrome (Ra 0,14 µm), nickel-chrome (Ra 0,17 µm), nickel-copper (Ra 0,18 µm) and it was slightly "micro-smoking" ("healed surface") (Fig. 23a, 24a, 25a). Preserves the surface layer of a similar nature in relation to the initial state - Ra 0,18 µm (Figure 17). The surface layer of the copper coating (without sublayers) - Ra 0,27 µm, has been similarly as in the case of the sample in the form of a disc which has been significantly development (Fig. 26).

- The x-ray microanalysis points of the samples showed the disc profile chemical composition of the individual galvanic layers and the substrate.

On the cross section the layers of the sample with coating nickel-nickel-chrome and nickel-chrome indicated that a chromium layer with a thickness of 0,4 µm is too thin to perform any accurate measurements. Accuracy of measurement for an x-ray microprobe is 1 micrometer. Attesting to this is shown in the presence of Ni, Ca, Cu, Al, S, Si, which comes from layers adjoining to the layer of chromium (Tables 8 and 9).
Energy spectra obtained from the nickel layers for all the samples showed trace amounts of flat iron which indicates contamination of the bath nickel ions of iron (III). The phenomenon of contamination nickel ions iron bath is a natural process, but the contamination has its limit values and it is 50 mg/dm³.

The analysis micro-area points for the glossy copper layer (sample with coating nickel-copper) for two measuring points 1 and 2 showed no additives other than metallic elements. The presence of nickel in the ground is noticeable on the border of the substrate - a layer of point 5. This may indicate the single migration of nickel ions in the surface layer of the substrate (Fig. 42, Tab. 10).

In the layer of copper matte (a sample of copper without a sub-layer) recorded a presence of Fe on the border of the substrate with a layer of copper - measuring point 2 (Fig. 43, Tab. 11). The reason for this may be the emergence of a complex cyanides of iron in a cyanide bath, informing about the contamination.

- Potentiodynamic tests for samples with the geometry of the disc indicates that the body fluids have a different aggressiveness with respect to the metallic coatings. The potential of the metal is a measure of its "nobility" in the electrolyte. The higher the value of the corrosion potential the greater "nobility" of metal.

The surface modification coating nickel-nickel-chromium, nickel-chromium, nickel-copper and copper resulted in a change of $E_{kor}$ - corrosion potential.

It was found that the lowest $E_{kor}$ (-539 mV) shows a sample No. 08 (without modification) in Ringer solution - Table 13.

The use of coatings on steel resulted in an increase of $E_{kor}$ modified samples. The highest increase of $E_{kor}$ relative to an unmodified surface of the substrate has a sample 39 (nickel-copper) by more than 456 mV. In comparison to the other coatings its nickel-copper coating has the highest values $E_{kor}$.

The lowest $E_{kor}$ potential (-486 mV) in Ringer solution for coatings applied showed sample 16 (nickel-nickel-chromium).

Exposure of samples (24 hours) in body fluids resulted in a change in the cathode current density at a potential -750 mV - ($E_{kor}$ -750 mV). The observed changes can be explained by the change of speed of the electrode processes occurring on the surface of the substrate and the coating. These changes indicate that the modified surface of the substrate affects the current density of the cathode at a potential -750 mV ($E_{kor}$ -750 mV)

The highest value ($E_{kor}$ -750 mV = 2,12·10⁻⁴ A/cm²) with respect to the substrate (1,07·10⁻⁴ A/cm²) as well as the remaining coatings shows sample No. 36 (nickel-copper) in Ringer's solution. This layer behaves similarly in the artificial saliva solution as in the artificial blood.

Changing the potential transition cathode - anode ($E_{kor}$) shows the dynamics of electrode processes occurring at the boundary metal phase- the body fluid.

The measured values of the potential transition cathodic - anode $E_{kor}$ the substrate without the coating and in various security configuration metallic coatings in Ringer's solution after a 24-hr exposure which indicates that the type of coating used to move the $E_{kor}$ in the direction of the more positive values of about 320 mV. The reason for this is to form a layer containing the appropriate barrier properties.

Polarization resistance $R_p$ shows the nature of the activity of body fluids. The observed changes in polarization resistance due to the difference in the chemical composition of the coating. The exposure (24 hours) modified substrate showed that the highest resistance $R_p$ (4,93·10⁴ Ωcm²) reached nickel-nickel-chromium coating in the artificial saliva solution, whilst the lowest value of the polarization resistance (1,20·10⁴ Ωcm²) has a copper coating without a sub-layer in the artificial blood solution.

The measurement of the corrosion rate to any metal in a corrosive environment is the corrosion current density $i_{kor}$. The higher the density the more quickly $i_{kor}$ corrosion processes follows under any given circumstances.

The highest corrosion rate ($i_{kor}$ = 1,18·10⁶ A/m²) found for copper coating without a sub-layer of solution of artificial blood. However, the slowest ($i_{kor}$ = 4,65·10⁴ A/m²) corrosion process occurred in a solution of artificial blood for nickel-copper coating. This confirms therefore that a high degree of development of the surface layer negative effect on the corrosion resistance of the coating. For copper coating without a sub-layer the roughness coefficient $R_a$ of 0,24 µm, is twice as high as the other coatings.

In summary, potentiodynamic research showed that the most resistant of the coating to the effects centers corrosive are coatings, which have the lowest degree development of surface layer and they are: for artificial blood - nickel-copper coating ($i_{kor}$ = 4,65·10⁴ A/m²) for artificial saliva solution - nickel-nickel-chrome coating ($i_{kor}$ = 5,29·10⁴ A/m²), for Ringer's solution is a nickel-chrome coating ($i_{kor}$ = 1,43·10⁴ A/m²) - Table 13.
Social benefits doctoral dissertation in the field of medical equipment protection from corrosion is shown in the following points:

- A high degree of development of the surface layer of the protective coating which has a negative effect on the corrosion resistance is an example of a copper coating without sub-layers with the highest roughness factor of $0.24\mu m$, this confirms the effect of roughness on the corrosion resistance despite the fact that the coating was the thickest coating of $29.7\mu m$ from among the tested;

- maintaining a continuity of coatings with a low coefficient of roughness improves the corrosion resistance of the coating refers to nickel – chrome $0.14 \mu m$, nickel-chromium $0.11 \mu m$ and nickel-copper $0.12 \mu m$;

- economic aspects
  - the application of metallic coatings with a surface layer of copper of a high gloss and low coefficient of roughness will increase corrosion resistance,
  - application of a coating of a surface layer of copper will contribute significantly to a decrease in the number of people hospitalized who are re-infected in hospitals,
  - copper has antibacterial properties, which ensure the maintenance of medical equipment in aseptic conditions;

- environmental aspect
  - the application of protective coatings with very low coefficient of roughness enable longer life medical equipment.
CONCLUSIONS

Protective coatings metallic found in hospitals are mostly coatings type nickel-chrome. The reason for using this type of coatings is it is easy to maintain aseptic medical devices. However, the continuity of how and the low roughness of such a coating is a guarantee to maintain high standards of hygiene in hospital conditions.

The research is focused on the selection of coating which would meet the expectations users of medical equipment both in terms of corrosion resistance and antibacterial.

The object of research was the bed rehabilitation, where local corrosion was found. The corrosion products contain a many elements indicating the cause of the destruction of the coating. The identified elements calcium, chlorine, potassium, carbon, sodium, aluminum, magnesium, sulfur, are components of body fluids blood, saliva, of meals remnants, but also of disinfectants. Conducted observations exploited medical equipment in hospital conditions confirmed the existence of this type of pollution on protective coatings.

The appearance of corrosion is also a health hazard or even life threatening to patients with reduced immune resistance. Because it has been shown that corrosion is a good place for locating dangerous strains of bacteria and fungi.

The application of metallic coatings with a surface layer of copper of a high gloss and low coefficient of roughness will increase corrosion resistance.

The application of a coating of a surface layer of copper will contribute significantly to the decreases in the number of people hospitalized who are re-infected in hospitals.

Copper has antibacterial properties, which ensure the maintenance of medical equipment in aseptic conditions.

The applications of protective coatings with very low coefficient of roughness enable longer life medical equipment.

Light of the foregoing selecting a coating of nickel-copper is the best solution for the protection of medical equipment from corrosion and also an excellent antibacterial protection in the context of protection of human health of hospitalized.
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