Current Condition and Development of Electrolytic Methods for Preventive Plating and Reconditioning of Worn Machine Parts

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Abstract: *In this Article, the perspective method of reconditioning of worn machine parts – application of electrolytic reconditioning coatings is discussed. Classification of these coatings is given on the base of various criteria: composition of the coating; properties; method of application. The most widely used reconditioning coatings of pure metals, conversion and composite coatings used for reconditioning of worn machine parts of equipment in agriculture, forestry, transport, road construction and quarry industries, are discussed*

Keywords*: Electrolytic Coating, Repair Coating, Electrodeposition of Metals and Alloys*

INTRODUCTION

In general, the automotive industry is one of the most important customers for the electroplating and surface treatment industries and it is an initiator of many research developments [6]. It is obvious that the galvanic coatings often are used for decorative purposes and with these important uses they have good cohesion with the base material, colour solution and good corrosion resistance. The Cu-Ni-Cr decorative coatings and coatings of precious metals have good cohesion and can be applied using new developments and other machine parts of magnesium / lithium alloys. The magnesium / lithium alloys are ultra-light alloys on the base of lithium alloyed magnesium. They have low densities and weights, good ductility and moulding properties, provide good welding properties, and have good corrosion resistance properties.

The reconditioning of the machine parts as an element of the general technological process of machine maintenance has some characteristics which differentiate if from the other stages (disassembly, cleaning, inspection, completing, assembly, testing and painting). The maintenance and reconditioning industry includes various methods, technologies and equipment for reconditioning of worn-out machine parts. Today, it is possible to remove practically all defects with few exceptions.

The restoration of the geometric sizes and / or the shapes of working surfaces of worn machine parts can be performed by various methods: application of various metallic or non-metallic coatings (build-up welding, electrolytic, electrophysical, polymeric and other coatings) or using repair sizes, additional machine parts, redistributing the material on the worn out machine parts, etc. [2,10, 13,14].

The most machine parts in the equipment for agricultural, automotive / tractor, transportation and road construction industries are of small sizes of 20… 50 (100) mm and worn values of 0.1… 1.0 mm. They work with high loads and these loads vary during the operation in terms of value and character of interference [8, 9]. Because of this, the reconditioning of large part of the worn machine parts in today’s equipment can be performed by electrolytic plating.

By appropriate selection of the reconditioning coating it is possible to increase significantly the durability and reliability of the worn machine parts. With the reconditioning of the machine parts, extension of the life cycle of the products can be achieved and this is a perspective area to achieve significant cost saving for materials, energy and environment protection.

EXPOSITION

Currently, method of testing of inter-industry changes in galvanic coatings and technological processes is used. Together with the major customers of galvanic production, new customers emerge, for example in medical equipment industry, microgalvanic plating, nanotechnology, which have their abilities. The composite coatings in modular multi-layers of control compositions discover perspectives for new composite materials as well as composite coatings with modified properties achieved using solids injected into the coatings [8, 7]. The contamination resistant surfaces and reviving cadmium coatings are of such interest. The electrolytic plating of metals as before represents modification method for the technical surfaces which gives various capabilities. Currently, this method is used combined with other earlier methods discussed as contrast methods. The surface treatment in the medical equipment area is a complex but very promising areas.

Three types of coatings are differentiated according to the requirements for the operation features of the machine parts:

- Protective – used to provide corrosion protection for the machine parts in various aggressive environments.
- Protective and decorative – used for decorative purposes and together with this function, they protect the machine parts against corrosion.
- Special – used to provide special properties of the machine part surfaces (wear resistance, solderability, hardness, electrical insulation and magnetic properties, etc.).

In some cases, the galvanically reconditioned machine parts show higher cost efficiency than these reconditioned by other applicable methods.

Of the large number of electrolytic coatings in maintenance industry, mainly the chrome plating, steel plating, nickel plating and in some cases, copper plating and tin plating are used.

Application of reconditioning electrolytic coatings is a perspective method for reconditioning of worn-out machine parts and it has a number of advantages compared to other methods:

- Possible application of reconditioning coatings of exact thickness and high uniformity.
- Possible application of reconditioning coatings on machine parts of various materials.
- Possible restoration of the machine part sizes without additional machining.
- Does not provoke thermal deformations or phase conversions in the machine parts.
- Possible simultaneous reconditioning of groups of machine parts.
- Possible application of composite coatings of various metals and alloys without intermediate machining.
- Possible application of coatings on machine parts of complex configurations.
- Possible restoration of the sizes and shapes of worn machine parts and improving the frictions and physical and chemical properties of these machine parts.

The reconditioning electrolytic coatings show great diversity and they can be classified according to their various properties: coating composition; properties and method of application. According to their compositions they can be separated into the following groups: single metal coatings, coatings of alloys of two and more metals, composite coatings, conversion coatings, polymeric coatings.

In Europe, the use of some metals is prohibited. In electroplating industry, this prohibition is applicable for the processes of six-valence chrome plating which encourages the development of alternative methods. For example, in the commercial process, the use of silanes is registered and these are described as polymeric coatings of zinc with titanium and zirconium chlorides. However, the application of nanoceramic coatings, including zinc silanes, does not include the whole spectrum of the use of the chromium plating processes using chrome compounds. The correct working method is to provide investigations for the efficiency of any of the methods in each case.

As first application, coatings of pure metals: chrome, iron, nickel, zinc, copper (Cr, Fe, Ni, Zn, Cu, etc.) are used for reconditioning of worn machine parts.

Chrome plating is one of the oldest galvanic processes used during the reconditioning of worn machine parts [2, 3, 5, 8, 10, 13, 15, 16]. Chrome plating is used for protective and decorative applications. In case of replacement of the sulphate with chloride in chrome-containing electrolytes, the current output is increased; however in this case, the anode corrosion is increased. In order to increase the corrosion resistances of the lead anodes, 2.7 % Sn, 2.5 % Zn, and 0.8 % Fe shall be included in the content. The whole spectrum of the required properties of hard chromium coatings is not possible to be provided using competitive methods and therefore one must not rely on the refusal to use hard chromium coatings [7, 11]. American authors keep other opinions that the chrome coatings will be replaced by chemical nickel coatings or hard powder coatings WC / CoCr. Friction properties of the chromium coatings in the chromium plating processes can be adjusted by modifications of the process parameters (temperature and current density) which impact the surface morphology. Pipes, bars, shaped products can be plated with hard chrome if they are connected mechanically and electrically. If we string together the piston rings for chromium plating on a bar the high length of the electrical contact between the rings would have an impact on the internal current resistance. Mechanisms for releasing chrome from chromium solutions of oxide or phosphate base are investigated. If is defined together with very complex processes and kinetic relationships which can be described using mathematical models.

The current density and bath temperature have large impact on the chrome plating process and deposition quality. The increase in the current density increases the current output and the increase in the temperature decreases it. To achieve quality chromium depositions it is necessary to maintain certain ratios between the current density and temperature. The parameters of the pulse mode and temperature impact on the hardness and carbon content in the hard chromium coatings. According to the used electrolyte and electrical plating mode, shining, milk, grey and porous coatings with desired friction properties can be achieved. The milk coatings have comparatively low hardness – approximately 400 to 600 HB. They are characterized also with that they are sufficiently ductile and wear resistant. No cracks present on their surfaces. The shining coatings have high hardness (600 to 900 HB), wear resistances, porosity, significant brittleness and have thin fibre-like micro-cracks. The mat coatings have low wear resistances and very high brittleness and hardness (900 to 1200 HB). Most suitable for reconditioning of worn machine parts are the shining coatings because of their high densities, wear resistances and reliable connection with the base material. The plating rate during the chrome plating process is comparatively low (0.02… 0.04 mm/h) because of the lower current utilization rate (13 … 18 %) and the maximum thickness of the reconditioning coating is comparatively low (01 .. 0.3 mm). There is also another type of chrome plating used for machine parts operated frequently in boundary friction conditions. This is the porous chrome plating. Its main advantage in comparison with smooth (hard) chrome is that it retains the lubrication layers well. This prevents the machine parts from dry and boundary friction and increases their wear resistance. The porous chrome is achieved using combination of high current density and low temperature. The precondition for the production of pores is the presence of micro-cracks in the ordinary coatings. In case of additional anode treatment, they are widened and deepened resembling channels.

Iron plating is also widely used for reconditioning of worn machine parts [2, 3, 5, 8, 9, 10, 12, 13, 16, 17]. The iron reconditioning coatings have high hardness values (6500 … 7000 MPa) and high wear resistance especially in the boundary lubrication conditions. This is explained with needle-like crystal structure and fast formation of oxide films during the friction process. There are several reasons for the increased interest to the iron plating. The electrolyte iron can be achieved easily – from available materials at low cost. It can be plated as a hard metal (5000 … 6500 MPa) which during the heat treatment will be converted into soft and ductile material. The physical and chemical properties of the coatings can vary widely according to the electrolysis conditions. The iron surface can be carbon plated, boron plated or nitride hardened. The electrolyte iron can be easily welded, plated on cast iron, copper, steel and other metals could be plated on it. The plating rate is one of the highest among the electrochemically achieved metal coatings: 0.2… 0.4 mm/h. During the recent years, the interest to the electrolytic iron increases because of its high wear resistance in boundary lubrication conditions.

The chloride and sulphate electrolytes are most commonly used for application of electrolyte iron. The electrolytes are produced from available materials and at low cost, 6 to 7 times lower than these for chromium plating. For example, we can produce chloride electrolyte for iron plating by dissolving swarfs of soft steel in hydrochloric acid. An advantage is the application of this method for removal of process rejected material during machining of machine parts and also for removal of 1.2 – 2 mm wear layers, restoration of clearances in movable joints, strengthening working surfaces, etc. The application of thick coating is cost-effective in case of large and expensive machine parts.

Another advantage of the iron plating is the significantly lower harmful properties of the electrolytes due to the lower risk of the presence of iron ions in waste water since they can present in dissolved condition only in acid environment. The typical acidity of the waste water results in formation of deposits of iron hydroxides which allows easy removal of them by deposition and filtering. The various metal and metal oxide coatings have significant impact in the general system for protection of machine parts and machine parts against corrosion.

The physical / chemical and operational properties of the iron reconditioning coatings can vary widely according to the electrolysis conditions and environment. The following are the uses as main control parameters of iron plating process: current density (Dk, A/dm^2); electrolyte temperature (t, °C), electrolyte acidity (pH); concentration of iron ions in the electrolyte (C_{Fe}). In case of low current densities, high electrolyte temperatures and concentrations, soft and elastic coatings can be achieved. With the increase in the current density and decrease in the electrolyte temperature and concentration, the hardness and wear resistance of the coatings increase. The plating mode must be selected according to the working conditions for the reconditioned machine part.

Particularly perspective area for control of the physical and chemical and operational properties of the achieved coatings is the use of alternate and pulse current and with the adjustment of current parameters, coatings with required (preset) structure and properties can be achieved.

The electrolytic coatings of **nickel, zinc and copper** are used in protection and decorative applications and as technological substrata for reconditioning of worn machine parts [2, 3, 5, 7, 8, 10, 12, 13, 16, 17, 18]. For application of such coatings, mostly simple electrolytes based on mineral acids are used. Normally, the electrolytes contain the following components: metal salt (chloride, sulphate, boron-fluoride etc.), substances increasing the electrical conductivity of the electrolyte, substances stabilizing the acidity of the electrolyte, substances improving the solubility of the anodes and shining generators.

In the maintenance practice, **nickel plating** is used as auxiliary or primary coating. In the first case, the nickel plating is used to create substratum before the chrome plating and in the second case it is used as an anti-corrosion measure. The thickness of the nickel coating with which the poreless layer is achieved depends on many factors (coarseness of the machine part, type of the electrolyte, etc.) and normally it must not be higher than 20 … 30 µm. In order to save the expensive and scarce nickel, normally composite coating is applied together with the copper which forms poreless coatings. The most common variants are: **Ni-Cu-Ni** (3 µm - 25 µm - 10 µm); **Ni-Cu-Ni-Cr** (3 µm – 25 µm – 10 µm – 1 µm) [3]. The Nickel coating of high hardness has good wear resistance and it is used for reconditioning of worn-out machine parts. The galvanic nickel coatings encourage the improvements of the soldering ability of the ceramic and metal machine parts. The operation life of the cutting tools increases after thermal / chemical and PVD treatment and also the operation life of the tools which give the shapes after coating by diffusion method. The ceramic coatings improve the friction properties of the aluminium. Large micro-structured moulding tools (e. g. micro dosers for liquids), for manufacturing complex plastic machine parts, are achieved using galvanoplastic application of nickel [7].

Hard electrolyte nickel plating is used for reconditioning of machine parts with surface hardness not higher than 400 HB. It is used for bearing beds and their dimension shall be converted to normal dimensions. This implies that the nickel plating can be used together with the chrome plating. The hardness of the nickel coating depends mostly on the electrolyte temperature, acidity and phosphorus content in the deposited metal. The hardness increases with the decrease in the temperature and with increase in the acidity [8].

Chemical nickel plating is widely used because of its many of advantages. Subject of this study is the deposition of nickel – chrome – phosphorus alloy which must replace the corrosion protecting and decorative nickel – chrome coatings. Many authors discuss the issues for producing chemical nickel coatings without lead or cadmium contents [6, 7]. The nano-coatings of nickel – molybdenum – boron and cobalt – molybdenum – boron achieved by recovering dimethyl boron are interesting. The corrosion resistant iron – zinc alloy is achieved by contact method with joining cupper substrata to aluminium strips. A process is designed and it can be used in practice. A patent should be mentioned where the metal and recover solutions are separately plated as powders on the substrata surface where they interact between each other. The nickel deposition process itself is not studied completely yet. The chemical deposition of nickel is possible only on metals which are catalytically able to impact on the nickel ion recovery reaction. Such metals are nickel, iron, aluminium, etc. Nickel can deposit on other metals using intermediate stratum, e. g. iron or the metal shall be activated in any other way.

Electrolytic copper plating is applied in case of reconditioning of worn bronze machine parts and application of substratum in decorative protecting chrome plating, nickel plating and a number of special cases [8]. The use of copper strata in chrome and nickel plating reduces the porosity of the composite coatings and labour costs of preparation operations. The advantages of the electrolytic copper plating include the availability and cheapness of the components. The bath is characterized with stable operation; however, the essential disadvantage of the method is that the adhesion of the copper coating to the steel or cast iron surface is very low. The fact by which this disadvantage can be explained is that in the time of submerging of the steel part in the bath, a thin copper layer is deposited on it with loose and porous structure which cannot act as a base for deposition of the electrolytic copper. This disadvantage could be eliminated using copper plating on the machine part firstly in cyanic electrolytes.

Zinc coatings. The investigations in the area of depositions of zinc and its alloys are used as a basic corrosion protection and they are applied mainly for protection of machine parts of ferrous metals against corrosion (screws, nuts, equipment operated in aggressive environments, as a substratum for light paint coats, etc.). In order to increase the corrosion resistance of **Zn** the coatings can be chromated or phosphated. The advantages of the electrochemical application of zinc coating compared to other methods (submerging into meted **Zn**, thermodifussion, gas-flame) are the following: high **Zn** purity, higher corrosion resistance due to the high purity, low material consumption and possibility for exact adjustment of the coating thickness, good mechanical properties [8].

Copper coatings are not used independently in protecting and decorative applications but in combinations with other coatings. The disadvantage of the sulphate electrolyte for copper plating is that in case of submerging iron machine parts in the electrolyte, contact, and release of **Cu** takes place and Cu shows low adhesion with the base material. In order to prevent such processes, thin nickel substratum shall be applied as a rule or cyanide or boron fluoride electrolyte for copper plating shall be used. The copper coatings can be used for protection of the machine parts against carbon pick up during cementation (48… 60 μm), as a substratum during reconditioning of bronze machine parts (0.1… 3.0 mm) with subsequent application of antifriction coating, for protection of the machine parts against fretting wear (15 … 25 μm), etc. [8].

Conversion coatings are non-metallic coatings achieved by conversion of the external atomic layers on the metal surface of the machine parts into new, non-metallic forms with properties different from the main surface properties [2, 7, 8, 10]. These coatings are achieved chemically or electrochemically (anodizing, oxidation, phosphatizing, sulphatizing, etc.). During reconditioning of the machine parts, these coatings are used to provide protection of metals against corrosion and to improve the properties of the reclaimed working surfaces. Anodizing of the aluminium and its alloys is most commonly used method. The achieved coatings are required to improve the wear resistance, anti-fretting properties, corrosion and thermal resistance and also as a substratum for application of other electrolytic coatings. As a result of comparison between various methods of phosphating, technological differences are found for the processes and also different properties of the achieved coatings – amorphous and crystalline. In order to simplify the mixture with the concentrates with phosphating, these must be prepared as water soluble dry mixtures. The corrosion protection of the phosphate coatings can be improved using subsequent submerging of the main chrome compound and formation of complex compound with phosphates. As preliminary treatment prior the application of the varnish coating, a process based on the zirconium compounds is proposed to be replaced by three-cationic phosphating. In the proposed treatment method using zirconium and vanadium compounds in lowered temperature is possible to use also titanium.

Composite electrolytic coatings are produced for the first time in the beginning of 1920s. These coatings consist of metal matrix (electrolytic coating) with included up to 30 … 40 % metal powders, oxides, carbides, nitrites, boronides, compounds with layered structures (mica, graphite,), polymeric powders, etc. [1, 2, 8, 12, 13]. The powder inclusions in the coating increase the coating wear resistance and anti-friction properties dramatically. The composite coatings are achieved using electrolytic suspensions composed of liquid phase (electrolyte) and solid phase (powder-like material). During the mixing of the two phases, adsorption interaction takes place between these phases with which certain charge is transferred to the powder particles (most often negative charge) and the particles are injected in the produced coating. The produced coatings are used for reconditioning and increasing the resource of machine parts operated in sliding friction conditions.

One of the modern areas in the reconditioning of the machine parts using electrolytic coatings is the achievement of reconditioning alloyed coatings. During the production of **electrolytic alloys** we can control the physical / chemical and mechanical properties of the coatings in higher degree which we could hardly achieve with other types of coatings. Often, the properties of the produced electrolytic coatings are different from these of the metallurgically produced alloys [8].

According to the number of metals, they can be: double-, triple- and multi-component alloys. The properties of many of the alloys with known recipes [2, 4, 5, 8, 15, 16, 17, 18] are insufficiently studied which prevents their wide application for reconditioning and preventive plating of machine parts.

According to their designation they can be as follows:

- Wear resistant alloys (Fe-Ni, Ni-Cr, Fe-Cr, Co-Cr, etc.);
- Anti-friction alloys (Pb-Sn, Pb-In, Pb-Cu, Pb-Ag, Sn-Sb, Sn-Cu, Zn-Fe, etc.);
- Anti-corrosion alloys (Zn-Cd, Cu-Zn, Cu-Sn, Zn-Fe, Zn-Ni, Pb-Sn, etc.);
- Protecting and decorative alloys (Ni-Co, Ni-Zn, Ni-Cd, Au-Cu; Au-Ni, etc.);
- Alloys with magnetic properties (Ni-Co, Ni-Fe, Fe-Co, etc.)

CONCLUSIONS

The electrolytic reconditioning coatings are highly varied and they can be classified by various their properties using wide spectrum of machine parts to be reconditioned.

Very often, the chromium plating and iron plating are used as reconditioning coating because of the possibility to apply very hard and very wear resistant coatings without disturbing the structure of the base metal.

The alloyed and composite electrolytic coatings have special methods of application enabling significant improvement of the physical / mechanical and friction properties of the reclaimed machine parts. However they should be studied in detail.

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