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Hardening parts by chrome plating in manufacture and repair

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Abstract. In the engineering industry, galvanic coatings are widely used to prolong the service life of the machines, which contribute to the increase in the strength of the parts and their resistance to environmental influences, temperature and pressure drops, wear and fretting corrosion. Galvanic coatings have been widely applied in engineering, including agriculture, aircraft building, mining, construction, and electronics. The article focuses on the manufacturing methods of new agricultural machinery parts and the repair techniques of worn parts by chrome plating. The main attention is paid to the unstable methods of chromium deposition (in pulsed and reversing modes) in low-concentration electrolytes, which makes it possible to increase the reliability and durability of the hardened parts operation by changing the conditions of electrocrystallization, that is, directed formation of the structure and texture, thickness, roughness and microhardness of chromium plating. The practical recommendations are given on the current and temperature regimes of chromium deposition and composition of baths used for the restoration and hardening of the machine parts. Moreover, the basic methods of machining allowances removal are analysed.

1. Introduction

Electrochemical coatings with wear-resistant chromium are widely used for hardening and restoring parts of agricultural machines in the production and repair process. Depending on the operating conditions, the parts are grouped into three main categories that operate: 1) at constant loads (bolts, cylinder rods, pivots, etc.); 2) at dynamic loads (crankshafts, reduction gear shafts, turbine shafts, etc.); 3) at relatively low loads (cylinders, plungers, etc.).

Due to the low chromium friction coefficient (0.03-0.12) in many materials used in engineering, chromium coatings resist wear. They also demonstrate thermal and chemical resistance to aggressive environments. Chromium coatings are characterized by the high bond strength with the metal base of the coated machine part [1]. However, until now, in the chrome restoration practice of machine parts, there are problems associated with 1) the productivity of the process, 2) the covering and diffusing power of the used electrolytes, 3) the high electrolytes toxicity, 4) the physical, chemical and mechanical properties of chromium coatings. To ensure the high quality of coatings, the production method of chromium deposition in electrolytes with a lower concentration of salts is applied. This method is used at high current densities in less toxic electrolytes on pulsed and reversible deposition regimes.
2. Materials and methods

In the practice of industrial chrome plating, a universal bath containing chromic anhydride (250 g/l) and sulfuric acid (2.5 g/l) is widely used. The use of chrome plating electrolytes with the temperature of up to 85 °C does not cause any structural changes in the material of the hardened or repaired parts, which makes it possible to increase the wear resistance of the working surface fivefold.

However, a number of disadvantages of the electrolysis in universal baths has been observed. Firstly, it is the low efficiency of the production method. Secondly, an accurate maintenance of the components concentration ratio in the optimum range to ensure an acceptable diffusing and covering power and the reliability of the chromium sediment adhesion to the machine part surface in case of the current interruptions is required. Finally, the chrome coatings are highly hydrogenated. Moreover, when the chrome coating thickness is within 350-1000 microns, dendrites and outgrowths are formed on the surface, which leads to an increase in roughness and a significant decrease in the endurance strength and the ductility of chromium-plated parts.

Electrolytes with a low concentration of chromic anhydride (150-100 g/l) are used mainly to improve the wear resistance of machine parts. Such electrolytes support a higher chromium current output, an increased covering and diffusing power. The chromium coatings have a higher strength and wear resistance, while the low-concentration electrolytes are less toxic in comparison with the general-purpose electrolytes.

When chromium-plating is performed at the pulsed current, the current density is the most important factor for the diffusing power. The least important factor under the same conditions is the pulse ratio (its influence begins to increase at the ratio 1.4 to 1.5). When chromium-plating is performed at the reversible pulse current, the current density and the ratio of the cathode current amplitudes to the anodic currents and the time of their duration are the most important. When the current density is increased, the covering power increases at all forms of the polarization current. The covering power is higher in the dilute electrolytes than in the general-purpose ones.

3. Results and discussion

The following current modes are recommended for obtaining a high covering power in the dilute electrolytes: at the reversible pulse current, the duration of the cathode pulse should be 1.5-3 min, the cathodic to anodic pulse time ratio - 40-50 and amplitudes ratio of the cathodic to anodic current densities - 2 - 3. The optimal cathode current density is 160 -180 A/dm², the temperature is 60-65 °C. At the pulsed current, the duration of the cathode pulse should be 1.5-2.5 minutes, the impulse ratio - 1.0-1.15, cathode current density 140-160 - A/dm². In the general-purpose electrolyte, the current density can be increased up to 200-250 A / dm².

At field tests the machine parts such as shafts (length-1600 mm, diameter from 80 to 120 mm, roughness Rₐ, metal bases - 0.08 microns) have been used. It has been established that when the coating thickness is 60-70 microns, the uniformity of the coatings with a surface roughness of 0.09-0.10 microns (unevenness of 1-2 microns per meter of length) can be attained at the pulsed current with the 70-110 A/dm² density in the dilute electrolyte (the temperature - 60-63 °C, the pulse duration - 2.0-2.5 min, and the impulse ratio - 1.13 -1.17). At the reversible impulse current, the uniform coatings with low roughness are obtained at the cathode current density of 80-100 A/dm²; the cathode period of 2-3 min, the cathodic-to-anodic impulse time ratio - 50-60, and the cathodic to anodic current densities ratio – 2 - 3. The surface roughness is reduced when the cathodic-anodic ratio of the current amplitudes is increased from 4 to 6. When the direct current (25-50 A/dm²) is used at the temperature 55-60 °C, and the coating thickness is15-40 microns, the roughness and the unevenness of the coating (Rₐ) is higher and varies from 0.55 to 0.65 microns (3-5 microns per meter of length). When the coating thickness rises up to 85-90 microns, the unevenness of the coating increases up to 7-10 microns, and the roughness is up to 0.65-0.75 microns.

It has been established that the difference in thermal or chemical-thermal treatment of various samples with electrolyte coatings does not affect the properties of the coatings such as roughness,
microhardness and porosity. The roughness of the base metal and the cake thickness affect the coating most strongly. With the increase in the chromium thickness up to 0.08 mm, the surface roughness rises 1.5-2 – fold (Table 1).

Table 1. The influence of the initial roughness of the surface of the parts before chrome plating and the thickness of the chromium coating on the roughness of the chromium surface

| Roughness Ra, microns | Thickness, mm |
|-----------------------|---------------|
|                       | 0.01 | 0.02 | 0.04 | 0.06 | 0.08 |
| 0.15                  | 0.25 | 0.32 | 0.42 | 0.45 | 0.50 |
| 0.30                  | 0.48 | 0.60 | 0.65 | 0.72 | 0.81 |
| 0.50                  | 0.62 | 0.92 | 1.03 | 1.13 | 1.21 |
| 0.75                  | 0.92 | 1.20 | 1.35 | 1.45 | 1.50 |
| 1.35                  | 1.45 | 1.55 | 1.62 | 1.70 | 1.88 |

The growth of the coating thickness up to 350 microns and higher leads to the formation of dendrites. The roughness of the chromium-plated surface depends on the chromium plating regimes, and it increases with the growing current density and the decreasing temperature of the electrolyte. The increase in the initial roughness of the surface at the layer thickness of 0.22 mm reduces the hardness of the coating by 10% and increases the porosity by several times (Table 2).

Table 2. The influence of the roughness before chromium coating on the microhardness of HV (kg/mm²) and the porosity of chromium N (pcs/mm²)

| Chromium roughness, microns | 0.12 | 0.20 | 0.32 | 0.63 | 1.25 | 2.6 |
|-----------------------------|------|------|------|------|------|-----|
| Porosity of chromium, pcs/mm² | 3    | 4    | 6    | 7    | 9    | 11  |
| Microhardness, HV200        | 910  | 880  | 865  | 860  | 840  | 830 |

Galvanic coatings are unevenly deposited on the metal. The change in the shape of the surface in the longitudinal and transverse directions depends on many factors, such as the shape, the size and the quality of the machine parts before coating; the electrolyte composition, the electrodeposition regimes, the cathodes and anodes location, the coating thickness, etc. In most cases the wear-resistant galvanic coatings are subjected to the physical treatment, so they are deposited with the machining allowance. The main methods of the machining with the use of abrasive materials are grinding, honing, smoothing and polishing. Each operation has its own specific goal. The surface grinding can be used to check the strength of the sediment adhering to the base metal without the destruction of the machine part. The surfaces of the chromium-coated parts can be given the optimum roughness, with which the wear of the conjugated pairs will be minimal. A diamond with a sphere radius of 1.0-1.5 mm is used for hard coatings, a diamond with a sphere radius of 2.5-3.5 mm is used for soft coatings.

The machining time is determined only by the allowance, as the mechanized lapping can remove 5-20 microns of chromium per diameter in 5-10 minutes (Table 3).

Table 3. Effect of the size of the abrasive grain on the surface roughness

| Grain size, microns | 10  | 20  | 30  | 50  |
|--------------------|-----|-----|-----|-----|
| Roughness, mkm     | 0.062| 0.075| 0.092| 0.12 | green silicon carbide in paste |
|                    | 0.062| 0.072| 0.082| 0.12 | electrocorundum with oil        |
|                    | 0.035| 0.052| 0.072| 0.10 | electrocorundum in paste        |
|                    | 0.075| 0.085| 0.12 | 0.15 | green silicon carbide with oil   |
The technological sequence of the worn parts recovery by galvanic coatings depends on the defects type and consists of the following: the application of a continuous coating layer over the entire surface of the part or the local refilling of the defect with the isolation of the remaining surface with the appropriate materials and its subsequent machining.

The tests of the machine parts with the single application of the load on the entire cross section have shown that the parts operate with the uniform destruction of the metal both in the main and reconstructed coatings of the surface of the part. Therefore, the changes in the state of the surface layer as a result of coating do not affect the strength characteristics of the steel. In addition, certain wear-resistant coatings (chromium, steel, nickel coatings), which have weak strength and plastic properties, crack in the region of small elastic deformations of the steel at the beginning of the test, and, therefore, do not influence the subsequent tests. For these reasons, the strength of the base material of the coated parts does not change after machining before and after coating, as well as after tempering.

At the same time, the steel plasticity at the static torsion and the impact bending is reduced. It occurs due to the increased brittleness of the surface layer as the coating thickness and chromium adherence grow after the repeated tempering.

When the influence of galvanic coatings on the performance properties of the machine parts is determined, it is necessary to take into account such important factors as the physical and mechanical properties of the base metal and the state of its surface; the technological sequence of the coating deposition; the machining methods applied to the parts before coating, the methods of the coating treatment, and the operating conditions of the machine parts [2, 3, 4, 5, 6]. It is important to know what effect each factor has on the performance properties of the parts. Only then the techniques of the deposition of one metal to another can be properly controlled and the relative methods of mechanical and thermal treatment before and after coating, ensuring the reliability of the machine parts (endurance, wear resistance, etc.) under different operation conditions can be recommended.

The results of the industrial application of chromium on new parts and the restoration of chromium coatings with a thickness of 50 microns are shown in Table 4.

| Table 4. Covering the machine parts with chromium (50 microns) |
|---------------------------------------------------------------|
| The product (steel)                                           | Measurements (mm, Ø, L) | Quantity (pieces) | D_{av} (A/dm²) dev.el-t (stand) | Treatment per min (dev/stand) |
| Spools                                                        |                           |                   |                                |                                 |
| st.35                                                        | Ø 20L100                  | 40                | 80                             | 50/150                         |
| st.40X                                                       | Ø 200L320                 | 40                | 80                             | 50/150                         |
| st.45                                                        | Ø 80L200                  | 40                | 80                             | 50/150                         |
| Rods of hydraulic cylinders                                   | Ø 36L600                  | 10                | 50                             | 60/80                          |
| st.40X                                                       | Ø 80L800                  | 10                | 50                             | 60/80                          |
| Rods of hydraulic cylinders                                   | Ø 160L800                 | 25                | 35                             | 120/140                        |
| st.30XTC                                                    | Ø 200L750                 | 25                | 35                             | 120/140                        |
|                                                             | Ø 120L450                 | 25                | 35                             | 120/140                        |
|                                                             | Ø 120L650                 | 25                | 35                             | 120/140                        |

When agricultural machinery steel parts (30XTC, 35, 40X, 45) are chromium-plated in low-concentration catalyzed electrolyte at current densities from 25 to 100 A/dm², a shining coating with evenly-distributed metal deposition over the coating thickness as well as over the diameter and length of the hydraulic cylinder rod is obtained. There is a high uniformity in the thickness of the chrome coating with the rod length from 1000 to 4000 mm. No exfoliation, influx, blistering, peeling of the chrome coating including the places of mechanical burning have been observed.

Chromium coatings up to 250 microns thick were deposited in the low-concentration electrolyte on the chromium and steel ground surfaces along the thread and on the rods both at interruptive and non-interruptive chromium deposition modes. The aforementioned technique made it possible to estimate the possibility of repairing undersized parts (under-covered in the required thickness dimension
according to the normative technical documentation). The adhesion of the coating to the substrate was good. Such coatings withstood mechanical grinding, polishing, tapping. No delamination or rupture of the coating occurred. In some cases, the hydraulic cylinders rods with the diameter of 500 mm and the length of 4000 mm were chrome plated. No coating delamination or peeling was observed. The uniformity of chromium deposition was high both diametrically and longwise. The thickness of the coating on the new parts was 60 microns, while on the repaired parts- 200 microns.

The low-concentration solution is characterized by its ecological compatibility and chromium plating labor saving (especially on small parts). The gain in the coating time was observed on the oversized parts in the low-concentration solution.

Optimum chromium plating modes are as follows: \( I_k = 50-70 \, \text{A/dm}^2 \); \( T = 55-57 \, \text{°C} \); the volume current density \( \sim 1.5 \, \text{A/L} \); the chromium current output - about 28%; the chromium deposition rate (if the current \( I \) is 55 A/dm\(^2\), the chromium deposition rate \( V \) is 0.95 ... 1.1 microns/min; if the current \( I \) is 75 A/dm\(^2\), the chromium deposition rate \( V \) is 1.3 microns/min).

The coating maximum hardness was reached with current 60-70 A/dm\(^2\) within the hardness value of 1028 ... 1036 kg/mm\(^2\).

In production, the low-concentration electrolyte demonstrated a higher diffusing and covering power compared to the general-purpose electrolyte, which made it possible to obtain uniform shiny chrome coatings on large parts.

Multiple chrome plating in the dilute electrolyte and heat treatment regimes affect the mechanical properties of metals (such as steel 50X, 65X, X18H10T, 30HGSA and copper): the yield strength, the strength, the adhesion of the chrome coating to the substrate, the cyclic durability, the endurance limit (Tables 5-7).

### Table 5. Heat treatment before and after chromium plating

| Metal grades | Temperatures (° C) and heat treatment time (h) |
|--------------|-----------------------------------------------|
|              | Before coating                  | After coating                        |
| 40X          | 400 (2,5 h)                      | 400 (3,5 h)                          |
| 65Г          | 420 (2,5 h)                      | 420 (2,5 h)                          |
| 30ХГСА       | 250 (3 h)                        | 250 (3 h)                            |
| X18H10Г      | 250 (3 h)                        | 250 (3,5 h)                          |
| Copper       | 550 (1,5-2 h)                    | 550 (2 h)                            |

The chromium plating has been carried out in the dilute electrolyte at 55 °C and the current density of 50 A/dm\(^2\) (the regimes of the previous and subsequent heat treatment) (Table 6). The chromium coatings from the samples were removed in NaOH.

### Table 6. Strength of chromium bonding with a copper and steel base in multiple chrome plating

| Sample status       | Average values of adhesion strengths, MPa |
|---------------------|-------------------------------------------|
|                     | Steel             | Copper           |
| Chromium-plated     | 230               | 220              |
| 3-fold Chromium-plated | 240             | 220              |
| 6-fold Chromium-plated | 250             | 220              |

The relationship between multiple chromium plating and mechanical properties of the steel is shown in Table 7. The relationship between the strength of the adhesion of chromium plating to the steel 40X is shown in Table 6.
Table 7. Mechanical properties of steels X18H10T, 65G, 40H, 30HGSA in restorative chromium plating (the covering thickness - 200 microns)

| Sample status            | T_0, MPa | T_v, MPa | ext., % | c, %  |
|--------------------------|----------|----------|---------|-------|
| Original                 | 1050     | 1038     | 17      | 37.9  |
| Chromium-plated          | 1047     | 1028     | 16.1    | 39.7  |
| 3-fold Chromium-plated   | 1067     | 1045     | 16.3    | 50.85 |
| 6-fold Chromium-plated   | 1077     | 1060     | 15.7    | 46.1  |

It can be seen that the multiple chromium plating (in comparison with the single chromium plating) practically does not affect the mechanical properties of metals. The strength of the adhesion of chromium deposits to the base (on all steels) remains almost unchanged.

Single chromium plating (16%) changes slightly the steel endurance limit. 3-6-fold chromium plating changes the copper endurance limit by 21% and the steel endurance limit - by 23%. With multiple chrome plating, both copper and steel endurance limit decreases by 7-8%.

The conducted researches have shown that the multiple chromium plating practically does not affect the cyclic durability and the endurance limit of steels and can be used as a repairing technique.

4. Conclusion

Of all the forms of the polarization current, the pulsed and reversible impulse currents with the reduced concentrations of the electrolyte have the most intense effect on the parameters of the chromium plating, the structure and the properties of the coating. When the pulsed electrolysis is used, it is possible to control the composition of the chromium alloys components and to obtain combined two-layered chromium coatings with the specified properties (nonporous or porous) from a single electrolyte. Chromium plating at pulsed and reversible impulse currents is more economical than stationary electrolysis. By increasing the coating uniformity and reducing its roughness, due to the absence of the dendrites, it is possible to reduce the standard thickness of the coating significantly and exclude machining, which can be regarded an emerging technology in mechanical engineering.

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