STUDY THE EFFECT FACTORS ON CHROMIUM PLATING ON THE FRICTIONAL AND WEAR PROPERTIES OF MACHINE PARTS

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Abstract

This paper studies the influence of current density and solution temperature when chromium plating on the surface quality of machine parts through friction and wear characteristics. By the experimental results using modern equipment the authors find out the best suitable range of current density and solution temperature to improve the surface quality of machine parts. It is shown that the optimal current density used for chromium plating should be the range of 20 ÷ 30 A/dm^2 and the optimal solution temperature range should be 50 ÷ 60^{o}C. Plating at these ranges will create the shiny coating with the best wear resistance while still ensure the thickness of the plating. Experimental results are the additional scientific basis for theoretical research in order to evaluate the surface quality of machine parts.

Keywords: *Chromium plating; current density; solution temperature; friction and wear.*

1. Introduction

Materials engineering has been rapidly developing with the mission of studying the structure and designing new materials. However, materials engineering does not deal with the problems associated with changing and improving the properties of materials on the surface. The technological measures will create new surface layers for machine parts. However, the properties as well as the working ability of these layers in combination with the substrate material to reduce friction and wear in the surface area have gotten the most concern [1].

These days there are many technological methods to help improve the surface quality and lifespan of machine parts such as: thermalization, electroplating, etc. Especially, chromium plating has the beneficial effect of increasing surface's micro hardness, wear and chemical resistance, decorating as well as maintenance of worn machine parts after a long use [2].

Studying the influence of factors in the plating process such as current density, solution temperature and solution composition, etc. to improve the surface quality of the machine parts has an important role in practice. Some authors [3, 4] mentioned technological solutions about chromium plating to prolong the lifespan of machine

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parts. Evaluating the surface quality mainly rely on mechanical properties such as micro hardness, adhesion, etc. Xuan Huy et al. [5] deeply concerned a number of effect factors in plating process such as current density, solution temperature as well as composition of solutions to create a shiny coating that has high aesthetic and better adhesion to the substrate. However, inspecting the friction and wear characteristics of these above researches has still gotten few attention and results.

Therefore, by friction and wear experiments we mainly focus on studying the optimal current density and solution temperature to improve the workability and extend the lifespan of machines.

2. General theories of chromium plating process

Chromium plating is fundamentally different from other plating processes by the precipitation of metallic chromium from Chromic acid H_2CrO_4, not from a solution of the metal's dissolved salts. Precipitation of chromium in Chromic acid (chromium contained in the anion CrO_4^{2-}) often takes place in the presence of H_2SO_4, Fluoroboric acid HBF_4 and Hexafluorosilicic acid H_2SiF_6. These added acids act as catalysts. Chromium plating solution is very sensitive to dirt.

Several theories suppose that when chromium plating process takes place on the cathode step by step, from changing chromium Cr^{6+} (CrO_3) into Cr^{3+} (in Cr_2O_3) and then Cr^{2+} (CrO) and finally to metallic chromium [6].

$$2CrO_3 + 6H^+ + 6e \rightarrow Cr_2O_3 + 3H_2O$$
$$2Cr_2O_3 + 4H^+ + 4e \rightarrow 4CrO + 2H_2O$$
$$CrO + 2H^+ + 2e \rightarrow Cr\downarrow + H_2O$$
$$2H^+ + 2e \rightarrow H_2\uparrow$$

Muller theory states that in the zone near the cathode $Cr(OH)CrO_4$ is formed and decayed by the process:

$$Cr(OH)CrO_4 + H^+ + e \rightarrow CrCrO_4 + H_2O$$
$$CrCrO_4 + 2e \rightarrow Cr\downarrow + CrO_4^{2-}$$

Depending on the electrolysis mode, the chromium layer will have very different properties. Based on these properties, there are 3 kinds of chromium plating layers:

- Gray chromium coating that has poor physical and mechanical properties, so it is rarely used;
- Polished chromium plating that has high hardness and good impact resistance;
- Milk chromium plating that has the smallest porosity and best elasticity.

If divided by different functions, there are three types of layers of chromium plating: anti-corrosion chromium, protective and jewelry chromium and anti-wear chromium.

The chromium plating layer has a very fine crystalline structure. The polished chromium layer has the smallest crystals from 0.001 μm to 0.01 μm, the gray and milk chromium layer has larger crystals from 0.1 μm to 10 μm. The chromium plating layer contains 0.2÷0.5% oxygen; 0.03÷0.07% hydrogen and a little nitrogen. The higher the solution temperature is associated with the lower the current density and the smaller the volume of gas mixed with chromium. After plating, heat treatment at 300^oC can remove 80% of hydrogen from the plated metal.

The chromium plating layer has two structural forms: αCr and βCr.

- αCr has a density of 7.1 g/cm^3 and is tightly arranged;
- βCr with density 6.08 g/cm^3 is arranged less tightly.

Plating at high temperature and high current density will produce αCr that results in a shiny, hard chromium plating layer. Plating at low temperature and low current density mainly produces βCr for porous and poor adhesive gray coating. The βCr form is only stable at temperatures below 25°C, when the temperature is higher it will change to the more stable form of αCr and simultaneously release the absorbed hydrogen and shrink in volume, causing a network of interlaced cracks on the surface of the plating layer.

Cracks of chromium plating only appear when the thickness of layer has reached a certain value. Therefore, it is possible to control the porosity of the plating layer by the electrolysis mode and by the ratio of CrO_3/H_2SO_4 of the solution. Chromium plating using solution that contains the SO_4^{2-} anion is widely used in industry. The advantage of this technology is that we just need simple equipment and a small amount of solution so that it is easy for preparation while still ensures the technical requirements of the machine parts and bring great economic efficiency.

In addition to the metal material, the quality of the formed coating depends on the following important factors: the current density, the main components of the plating solution, the temperature of the solution, etc. Therefore, these above effect factors must be strictly controlled within the technological limitation.

3. Test sample and test procedures

3.1. Test sample

The material used to make the test sample is 65Г steel. The chemical composition of the sample is shown in Tab. 1 [7].

Tab. 1. Chemical composition of the test sample (%)

C	Si	Mn	Ni	S	P	Cr	Cu
0.62 - 0.7	0.17 - 0.37	0.9 - 1.2	maximum 0.25	maximum 0.035	maximum 0.035	maximum 0.25	maximum 0.2

3.2. Test procedure

The test procedure is shown in Fig. 1.

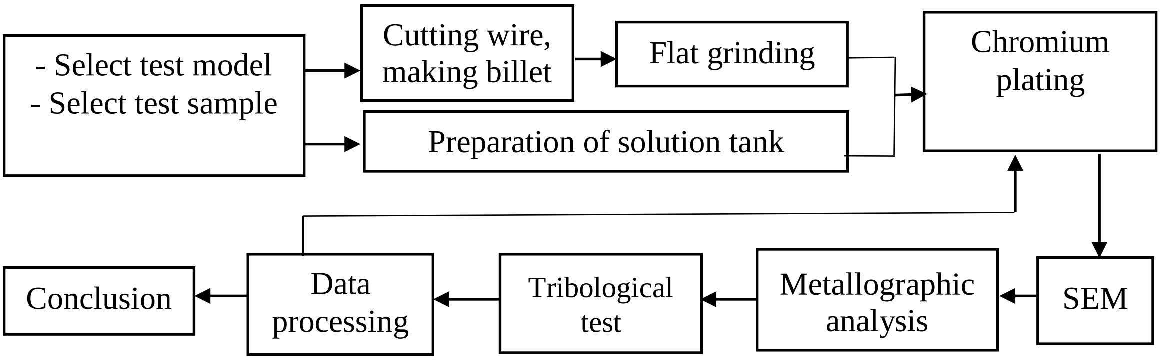


Fig. 1. Test procedure.

3.3. Solution composition and electrolytic parameters

The composition of the chromium plating solution is mixed according to the percentage as shown in Tab. 2 and the electrolytic parameters are shown in Tab. 3.

Tab. 2. Ingredients of Chromium plating solution

Ingredients	**Concentration, g/l**
CrO_3	250
H_2SO_4	2.5
CrO_3/ H_2SO_4	100/1
Density	1.18

Tab. 3. The value of electrolytic parameters

Electrolytic parameter	**Value**
Temperature T (^oC)	20 ÷ 70
Current density of Cathode D_c (A/dm^2)	10 ÷ 50
Plating time (s)	3600

3.4. Test apparatus

The equipment used to measure the test samples includes:

- Scanning Electron Microscope (SEM) JSM 6610LA, Joel brand, Japan.

- The device system for measuring Metallography are a Danish micrometer Duramin and a German microscope Axio Imager A2M.

- The device for measuring friction and wear is the Universal Materials Tester (UMT-3MT) system that is shown in Fig. 2. It is used for frictional testing of ferrous, non-ferrous, plastic, ceramic, paper, composite materials, thin coatings as well as solid lubricants, oils and greases. Force can be accurately measured from mg to kg with a resolution of 0.00003% of the scale. The obtained test data can be in the form of graphs, tables or mathematical equations [8].

Friction test modes include: Pin or ball on the plate/disc; Balls on 1 ball, 2 balls or 3 balls; Pin on Block V; Block on Ring; Disc on Plate; Screw in Nut [9].

4. Analysis and evaluation of test results of friction and wear

4.1. Model and test conditions

The test used ball on flat plate model shown in Fig. 3. The upper sample is a ball made of stainless steel 1X18H9T (0.1% C, 18% Cr, 9% Ni and about 1% Ti) and the other is a flat plate with surface roughness Ra = 0.32 μm.

- Reciprocating Frequency: 3 Hz;
- Loading force (Fz): 10 N;
- Test time: 5 minutes.

Fig. 2. UMT-3MT.

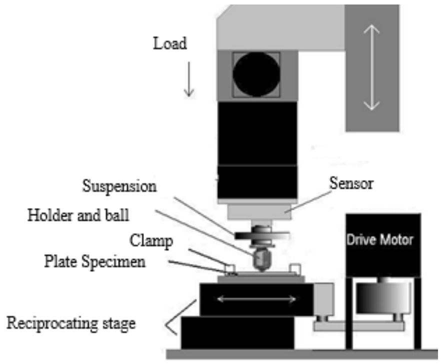


Fig. 3. Ball on flat plate model.

4.2. Investigating the effect of changing the current density

4.2.1. Test samples

The test samples were manufactured according to the changing of current density from 10 to 50 A/dm^2 and constantly keeping the plating temperature T = 55^{o}C. Tab. 4 shows the tested samples.

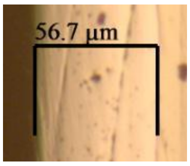
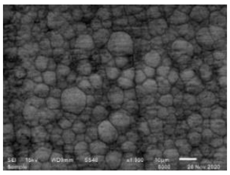
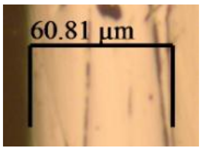
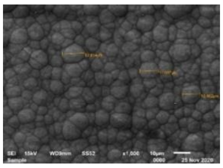
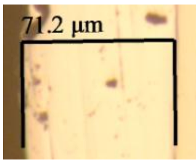
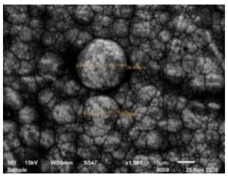
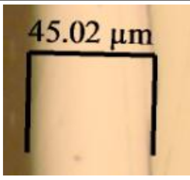
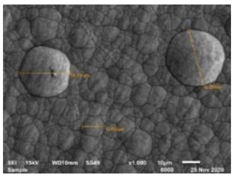
Tab. 4. Samples tested according to the changing of current density

No.	Name	Plating mode		
		Temperature T and current density D_c		Time t (s)
0	00	No surface treatment		
1	01	T = 55^{o}C	D_c = 10 (A/dm^2)	3600
2	02		D_c = 20 (A/dm^2)	
3	03		D_c = 30 (A/dm^2)	
4	04		D_c = 40 (A/dm^2)	
5	05		D_c = 50 (A/dm^2)	

4.2.2. Test results and reviews

Test results of samples are summarized in Tab. 5.

Tab. 5. Test results of samples when changing the current density

Sample	Micro Hardness (HRC)	The thickness of plating layer	SEM image	Coefficient of Friction	Wear depth (mm)
00	25			0.4043	3.21e-5*t
01	-	No forming plating coat	-	-	-
02	60.5			0.4714	1.39e-5*t
03	63.1			0.4517	1.16e-5*t
04	62.6			0.5760	1.50e-5*t
05	57.6			0.5635	1.86e-5*t

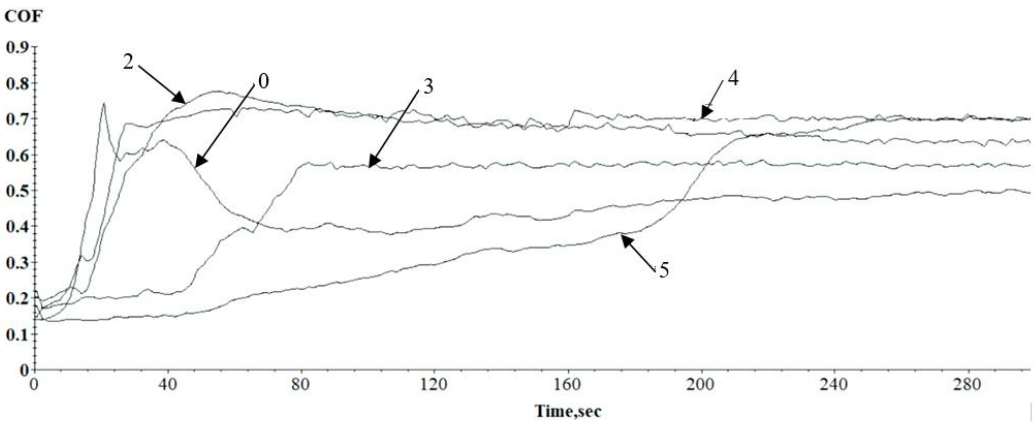


Fig. 4. Line graph of coefficient of friction (COF) of the test samples over time
0 - Sample 00; 2 - Sample 02; 3 - Sample 03; 4 - Sample 04; 5 - Sample 05.

From the experimental results (Tab. 5 and Fig. 4), it is shown that:

- When plating at a current density of Dc = 10 A/dm^2 (sample 01), there was only a very thin coating formed near the electrode zone, no plating layer formed in the middle of the surface. For this reason, it should not be used for plating the surfaces of machine parts at this current density. Therefore, sample 01 was not tested by SEM and measured friction and wear.

- For the remaining samples, after chromium plating they all had better wear resistance than sample 00 (sample without surface treatment). From Tab. 5, it is shown that the best wear-resistant samples were sample 03, 02, 04 and 05 which had the wear rate of samples by 1.16e-5, 1.39e-5, 1.50e-5 and 1.86e-5 mm/s, respectively.

- When plating at the current density between 20 A/dm^2 to 30 A/dm^2 (sample 02, 03), it created uniformly small grain size that had low coefficient of friction (0.4714 and 0.4517, respectively) and good wear resistance. The picture of SEM shown that the sample had the best surface quality at the Dc value = 30 A/dm^2.

- At current density Dc = 40 A/dm^2 (sample 04), the coating thickness increased to 71.2 µm. However, the grain size was much larger and coarser compared to sample 02 and 03. In addition, the coefficient of friction and the wear rate of coatings significantly increased to 0.5760 and 1.50e-5 mm/s, respectively.

- When plating at a current density of 50 A/dm^2, the thickness of coating was dramatically reduced to 45.02 µm, the micro hardness of surface was also slightly reduced to 57.6 HRC. Moreover, the formed coating had the largest grain size and the highest wear rate (1.86e-5 mm/s) compared to those of remaining samples. Therefore, this current density should not be used for plating.

4.3. Investigating the effect of changing the solution temperature

4.3.1. Test samples

From the test results in condition of changing the current density, we found out that the optimal current density value is 30 A/dm^2. Therefore, when making samples we keep this current density as a fix value and change the solution temperature in the range of 20^{o}C to 70^{o}C in order to find the optimal temperature for the chromium plating process. The test samples used to investigate the effect of changing the solution temperature are shown in Tab. 6.

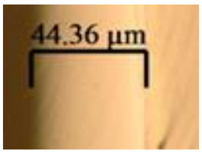
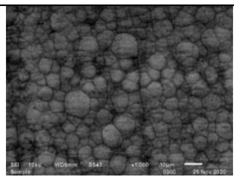
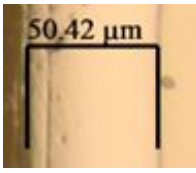
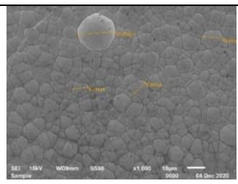
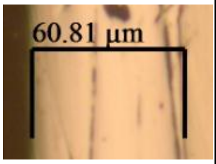
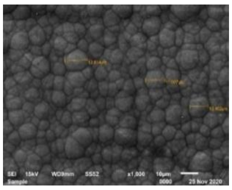
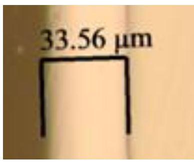
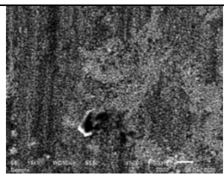
Tab. 6. Samples tested according to the changing of solution temperature

No.	**Sample**	**Plating mode**		
		Temperature T and current density D_c		**Time t(s)**
6	06	T = (20 ÷ 30)°C		
7	07	T = (30 ÷ 40)°C		
8	08	T = (40 ÷ 50)°C	D_c = 30 (A/dm²)	3600
9	09	T = (50 ÷ 60)°C		
10	10	T = (60 ÷ 70)°C		

4.3.2. Test results and reviews

Test results of samples are summarized in Tab. 7.

Tab. 7. Test results of samples when changing the solution temperature

Sample	**Micro Hardness (HRC)**	**The thickness of plating layer**	**SEM image**	**Coefficient of Friction**	**Wear depth (mm)**
00	25			0.4043	3.21e-5*t
06	-	Dark coating does not mount to the substrate	-	-	-
07	55.6			0.3765	1.86e-5*t
08	57.8			0.4604	1.64e-5*t
09	63.1			0.4517	1.16e-5*t
10	65.9			0.4201	9.34e-6*t

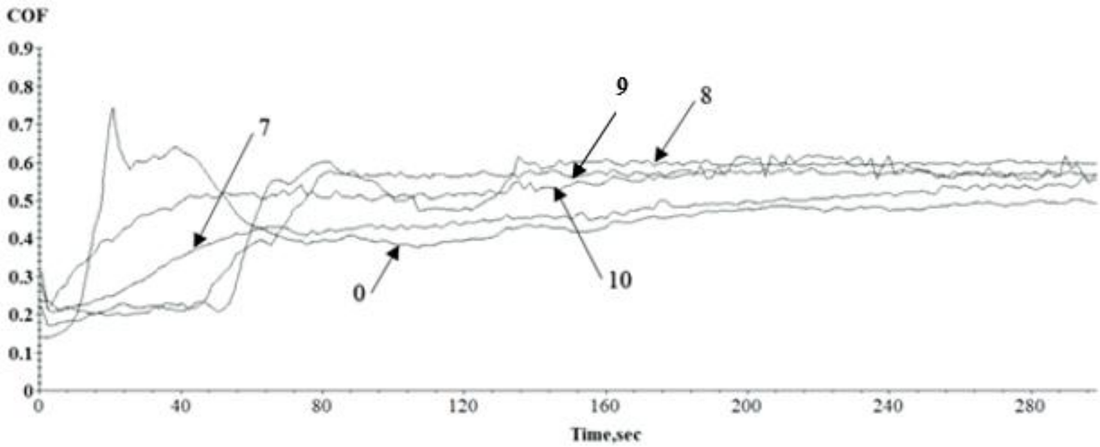


Fig. 5. Line graph of COF of the test samples over time
0 - Sample 00; 7 - Sample 07; 8 - Sample 08; 9 - Sample 09; 10 - Sample 10.

From the experimental results (Tab. 6 and Fig. 5), it is shown that:

- When plating at a temperature of T = 20 ÷ 30^{o}C (sample 06), the surface of the sample only formed a dark coating which did not mount to the substrate. For this reason, it should not be used for plating the surfaces of machine parts at this temperature range. Therefore, sample 06 was not tested by SEM and measured friction and wear.

- As the temperature increases, those above samples witnessed a raise of coating's micro hardness, wear resistance and thickness. Besides, the glossiness of the coating is also clearly improved.

- At the temperature range of 30 ÷ 40^{o}C (sample 07), the coating had matte gray color with low micro hardness by 55.6 HRC and a large grain size. It also had the lowest ability of wear resistance in dry friction condition compared to the remaining samples (its wear rate was 9.34e-6 mm/s). This temperature range caused a matte chromium coating. In addition, plating at low temperature would produce βCr which causes porous gray coating with low micro hardness and poor adhesion to the substrate.

- When chromium plating at the temperature range of 40 ÷ 60^{o}C (sample 08 and 09) samples had light color, uniform small grain size with low coefficient of friction and good wear resistance. The reason is that when plating at high temperature, αCr will be generated so it leads to form a shiny, hard coating and helps increase current efficiency.

- When plating at the temperature range of 60 ÷ 70^{o}C (sample 10), the sample had higher micro hardness by 65.9 HRC and better wear resistance compared to the remaining samples but there were many tiny cracks appearing on the surface of the plating layer. The reason is that when plating at a temperature exceeding the endurance of samples, it will cause the reduction of the current efficiency so that the thickness of the plating layer will reach its certain limit and finally form cracks that damage the surface quality of a machine parts.

5. Conclusion

Experimental results show the significant effect of changing current density and solution temperature on friction and wear characteristic of the surface of machine parts. It is clear that the optimal current density used for chromium plating should be the range of $20 \div 30$ A/dm^2 and the optimal solution temperature range should be $50 \div 60^oC$. Plating at these value ranges will create a uniform small grain size coating that has low COF and the best wear resistance while still ensure the thickness of the plating. These ranges of value found above are reliable for further study the influence of other effect factors in the plating process.

The experimental study is an additional scientific basis for the theoretical research to evaluate the surface quality of machine parts after chromium plating through friction and wear characteristics.

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NGHIÊN CỨU ẢNH HƯỞNG CỦA MỘT SỐ YẾU TỐ KHI MẠ CROM ĐẾN ĐẶC TÍNH MA SÁT, MÀI MÒN CỦA CÁC CHI TIẾT MÁY

Nguyễn Trường Sinh, Phan Văn Mạnh, Phạm Văn Nhất

Tóm tắt: *Bằng nghiên cứu thực nghiệm, bài báo đã xem xét ảnh hưởng của mật độ dòng điện và nhiệt độ dung dịch khi mạ crom đến chất lượng bề mặt chi tiết máy thông qua đặc tính ma sát, mài mòn. Từ các kết quả thử nghiệm trên các thiết bị hiện đại, nhóm tác giả đã tìm ra được các giá trị mật độ dòng điện và nhiệt độ dung dịch mạ tối ưu nhằm nâng cao chất lượng bề mặt chi tiết. Cụ thể, vùng mật độ dòng tối ưu sử dụng để mạ crom là 20 ÷ 30 A/dm*^{2} *và vùng nhiệt độ dung dịch tối ưu là 50 ÷ 60°C. Đây là vùng cho lớp mạ sáng bóng, khả năng chống mài mòn tốt nhất mà vẫn đảm bảo chiều dày lớp mạ. Các giá trị này là tin cậy để tiếp tục nghiên cứu ảnh hưởng của các yếu tố khác trong quá trình mạ. Kết quả nghiên cứu thực nghiệm là cơ sở khoa học bổ sung cho nghiên cứu lý thuyết nhằm hoàn thiện về đánh giá chất lượng bề mặt chi tiết máy.*

Từ khóa: Mạ crom; mật độ dòng điện khi mạ crom; nhiệt độ dung dịch khi mạ crom; thử nghiệm ma sát, mài mòn.

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