# Optimizing Coating Process Parameters by Using Taguchi Experimental Design to Increasing Wear Resistance of Steel CK50

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## ABSTRACT

The present investigation aims to increase the wear resistance for steel CK50 by using Hard Chromium electro plating process. The wear behavior of the specimen was investigated using pin-on-disk where the samples sliding against a steel disk under fixed conditions. The experiments designed according to Taguchi method several experiments have been carried based on an orthogonal array L9 with three parameters (time, current and temperature) at three levels (low, medium and high).The result of research based on the signal to noise ratio (S/R) depending on the condition smaller is the better approach, where the best optimal coating parameters have been arrived at (t2, A2, Temp1) i.e. time 20min, current 30 A/dcm2 and temperature 45 C° from the maximum values of average (S/N). Analysis of Variance (ANOVA) is applied to find out the significance and percentage contribution of each parameter. It has been observed that temperature has maximum contribution on Cr - coating process.

**Keywords:** Coating Process, Wear Resistance, Taguchi Method, S/N

# امثل العوامل لعملية الطلاء باستخدام التصميم التجريبي لتاكوشي لزيادة مقاومة البلى للفولاذ CK50

**الخلاصة**

تهدف الدراسة الحالية الى زيادة مقاومة البلى للفولاذ (CK50) باستخدام عملية الطلاء الكهربائي بالكروم الصلد . وكان التحقيق في سلوك البلى للعينات باستخدام Pin-on-disk حيث ان العينات تنزلق على القرص الصلب تحت ظروف ثابتة. وقد صممت التجارب وفقاً لاسلوب تاكوشي).( العديد من التجارب اجريت على اساس المصفوفة المتعامدة L9 مع ثلاث عوامل (الوقت ، التيار ودرجة الحرارة) على ثلاث مستويات (منخفضة ومتوسطة وعالية) بناء على نسبة الاشارة على الضجيج (S/N) اعتماداً على الحالة الاصغر هي الافضـــل. الظروف الامثل للطلاء (t2, A2, Temp1) أي الوقت 20 دقيقة التيار 30 امبير /ديسم $^2$ ودرجة الحرارة 45 درجة مئوية تم ايجادها من



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القيمة العظمى لمعدل الاشارة على الضجيج (S/N) . يتم تطبيق تحليل التباين لمعرفة اهمية ونسبة مساهمة كل عامل. وقد لوحظ ان درجة الحرارة لها تأثير اكبر على عملية الطلاء.

## INTRODUCTION:

Friction, wear and adhesion play an important role in determining the performances of industrial devices [1]. Most of the parts exposed to wear in engineering during loading. Wear is one of the most important three problems that lead to the damage of industrial engineering parts as well as fatigue and corrosion [2]. The wear properties of engineering materials have significant effects on the serviceability and durability of their components. Hence, the wear properties must be taken into account in the design of engineering parts. It is generally known that the wear resistance of metals and alloys is proportional to their hardness. The enhancement of the wear resistance of materials can be attained by various methods, typically heat treatment and surface coating [3]. Of large and important problems faced by a lot of machines with frequency movements or sliding is the problem of friction and wear because they adversely affect directly on the accuracy of the work and the performance of these machines as they affect the efficiency significantly. This is in addition to heavy losses as a result of repair and rebuilding of those devices[4].The aim of this work is increasing the wear resistance of steel CK50 rod to use in any rotating motor shaft by using Taguchi experimental design to select the optimal level of factors.

### Literature review:

Because all problems have been introduced previously, many researchers studying friction and wear to know their causes and the factors that affect them as follows.

S.Houdkova´etal.2011[5] the tribological properties of the HVOF-sprayed coatings and the plasma-sprayed $Cr_2O_3$ coating were compared with the properties of electrolytic hard chrome and surface-hardened steel. Four different wear behavior tests were performed; the abrasive wear performance of the coatings was assessed, the sliding wear behavior was evaluated by pin-on-disk testing according to ASTM G-99, and the erosion wear resistance was measured for three impact angles.

A.Baradeswaran etal. 2013[6] deals with the effect of $Al_2O_3$ on wear properties of AA7075 metal matrix composite and the results were optimized by Taguchi technique. The wear test was conducted with pin-on-disc apparatus with the controlling parameters were. The micro structural investigation on the worn surfaces was performed by Scanning Electron Microscope.

D. ZenebeSegu et al.2013[7] presents the results of the combination effect of solid lubricant and LST steel surfaces on the tribological properties. To improve the surface texturing effect on friction and wear, different multi-dimple patterns with some specific formula arrays were fabricated by laser ablation process by combining circles and triangles, and circles and squares on the surface of steel. The influence of normal load, sliding speed and texture area density on the friction performance of multi-dimple patterns was also investigated by the Taguchi method.

M.A. Shalaby et al.2014[8] illustrates the performance of three different cutting tool materials, namely: PCBN,TiN coated PCBN, and mixed aluminum ceramic(Al2O3þTiC) in the turning of medium hardened D2 tool steel (52HRC). Obtained results revealed that the mixed alumina ceramic tool can outperform both types of PCBN under different machinability criteria.

T.RamPrabhu et al. 2014[9] examined the effect of coating the SiC particles with BaSO4 to improve interfacial properties and prevent potential undesirable interfacial reactions. The wear loss was found to decrease with increasing volume fraction of SiC for all particulate sizes. At low sliding speeds the composites with large particle sizes and high volume fractions were found to be more effective in controlling wear.

Su-Jin Kim et al. 2014[10] new method of predicting diamond tool wear which combines experimental equations with statistics is introduced. The wear model shows the relation of cutting condition, safe wear and probability, which was built by the first experiment. The predicted average wear was the same as the measured value of the verification experiment and the probability was a little smaller than the verification experiment due to the bigger standard deviation of the first experiment, which was not stable compared to the verification experiment.

## Taguchi method:

The history of quality and methods is as old as the industry itself. However, modern quality methods were developed after the industrial revolution [11].It is common mistakes to assume that an experiment should be as big as possible, but if more data is collect than it actually need to address question effectively and waste time and money [12].

The Taguchi methods that were developed as an aid of quality assurance in Japanese industries are among the most powerful approaches to understand the process and optimize its performance. Taguchi described his methods as quality engineering. This assists the industrial engineers to prove near optimal quality characteristic or (response) for specific objective within determining the best combination of parameters. This can be achieved only by making the process insensitive to various sources of noise and the method is called robust parameter design [13].Taguchi addresses quality in two main areas: off-line and on-line quality control (QC). Both of these areas are very cost sensitive in the decisions that are made with respect to the activities in each. On-line QC refers to the monitoring of current manufacturing processes to verify the quality levels produced [14]. Off-line quality control has become quite the rage under the banner of Taguchi methods. The principle of off-line quality control is to put a product on target with minimum variation [15].

## Experimental Work:

The framework of proposed methodology of research as shown in Fig (1) the details of the experiment work can be explained in the following which contain all the steps of Taguchi method that used in the research.

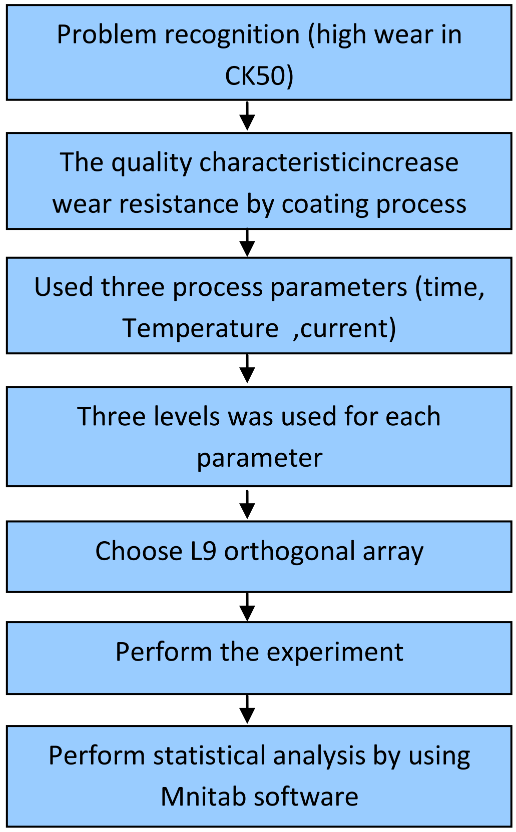


**Figure (1). Methodology of research**

**Work material:**

The work material selected in this investigation is steel CK 50 becausethis rod is a cheap and has good machining properties. The chemical composition of the material was analyzed in the Specialized Institution of Engineering Industries-Baghdad. Testing device is (SPECTROMAXx) and the chemical composition is given in table (1)

**Table (1). Chemical composition of steel CK50**

| Wt% | % C | % Si | % Mn | % P | % S | % Cr |
|---|---|---|---|---|---|---|
| | 0.538 | 0.232 | 0.872 | 0.0229 | 0.0257 | 0.241 |

**Design of experiments:**

Taguchi method is applied in the coating process to select the optimal parameters for the Industrial Hard Chromium Plating.This uses an orthogonal array to study the entire parametric space with a limited number of experiments.The four machining parameters (control factors) considered in this study are: time, current and temperature. All of them were set at three different levels (see Table 2). Therefore, an L9 orthogonal array is used (see Table 3).

**Table (2). Control factors**

| Levels of experimental factors | Experimental factors | | |
|---|---|---|---|
| | Time t(min) | Current A(A/dcm$^2$) | Temperature Temp C$^o$ |
| **1** | 10 | 20 | 45 |
| **2** | 20 | 30 | 50 |
| **3** | 40 | 40 | 55 |

The response variables chosen for the present investigation is wear rate. The lower-the-better quality characteristic has been used for calculating the signal to noise (S/N) ratio for these responses, see Eq. 1.[16]

$$S/N = -10 \log 1/n (\sum_{I=1} y^2) \quad \ldots (1)$$

Where:

I is 1 to n,

y is observed response value at each trail,

n is number of observations in each trail

**Table (3). L9 OA**

| Experiment no. | Column | | |
|---|---|---|---|
| | Time(min) | Current (A) | Temperature (c$^o$) |
| **1** | 10 | 20 | 45 |
| **2** | 10 | 30 | 50 |
| **3** | 10 | 40 | 55 |
| **4** | 20 | 20 | 50 |
| **5** | 20 | 30 | 55 |
| **6** | 20 | 40 | 45 |
| **7** | 40 | 20 | 55 |
| **8** | 40 | 30 | 45 |
| **9** | 40 | 40 | 50 |

**Experimental procedure:**

The experiment is doing in laboratories of Department of Production Engineering and Metallurgy. Accordingly the present study has been done through the following plan of experiment.

1-The first step in the experiment is cutting the material rod into samples that have (30mm length, 8.3 mm diameter) by using power saw.

2- Then the sample is drilled by the vertical drill to make a hole that need to connect the sample with the electrode by wire.

3-Cleaning it by immersing in the solution contain (NaOH 100g/L)

4-Then wash it with water

5-Immersing it in solution(50%HCl)

6-Good wash with water

7-Immersing in solution (1%$H_2SO_4$)

8-Wash with water

9-After cleaning process the solution is heated by the heater to the suitable temperature to run the experiment by using the ($L_9$ OA) that is explained in Table (3) and all runs were replicated to reduce the error in the experiment.

**Equipments Used:**

1.Electro plating system: The researcher designed this device to make the experiment by assembling different parts to make Electro plating system that explain in Fig (2).

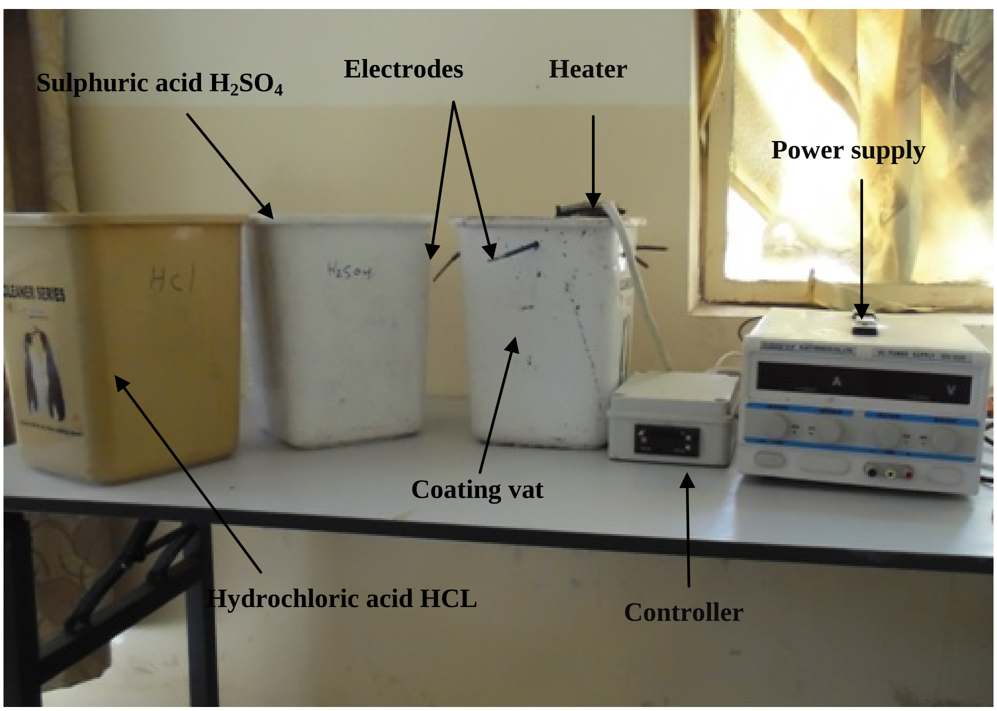


**Figure (2) Electro plating system**

A- Power supply.
B- Controller.
C- Coating vat.
D- Prepared Solutions.

- Chromic acid $CrO_3$(250 g/L).
- Sulphuric acid $H_2SO_4$(1%).
- Sodium hydroxide NaOH(100g/L).
- Hydrochloric acid HCl (50%).

2.Sensitive balance:(Mettler Toledo AB204-S/FACT Analytical Balance).
3.Coating thickness measuring: (Nikon Eclipse ME600) made in japan with digital camera type (DXMI 200 F) available in (Ministry of Science and Technology).
4.Wear Apparatus type ( Pin on Disc D2625 -83 (ASTM)). This deviceexplain in Fig(3).

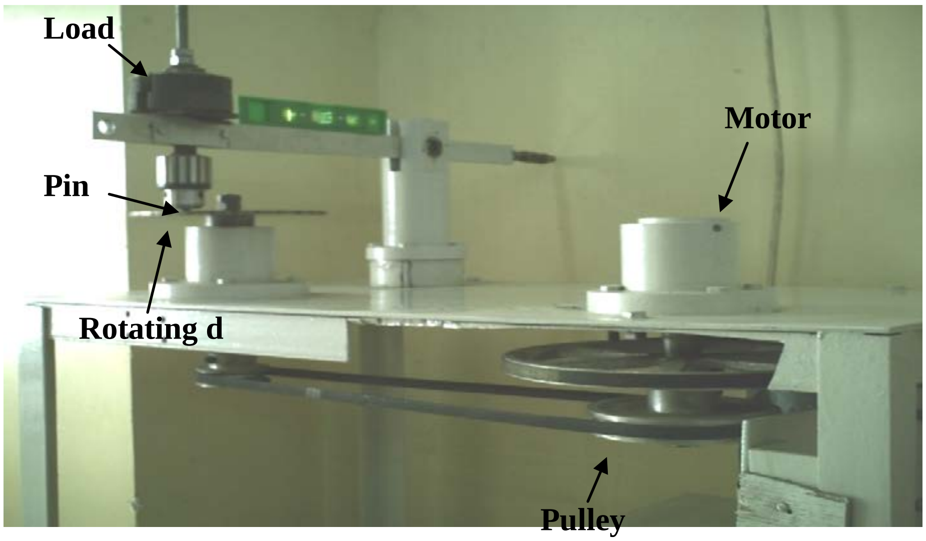


**Figure (3) Wear apparatus (Pin on Disc)**

**Wear Test:**

By using the wear rate device illustrated in Fig.(3)available in University of Technology, in this test, the variables that were used to perform the test are
1.Time = 20 min
2.Motor with rotational velocity (940 rpm)
3.The hardness of rotating steel disc is ( HRC 63 )
4.sliding speed = 3.7 m/sec
5.Load = 147 N
After fixing all factors the test was done in the following procedure

a. Weighing the specimen before test by using digital sensitive balance
b. Fixing the specimen by the bearer in vertical position on disc.
c. Fitting the operation time.
d. Checking the cleanness of the disc before the test start.
e. Operating the apparatus with fixing all variables.
f. Stopping the operation and weighing the specimen.
g. Repeating the process for all specimens

The wear rate is calculated from the following equation [17]

$$wr = \frac{\Delta w}{2\pi r n t} \quad \text{…. (2)}$$

where:
$\Delta w$ is $w_1 - w_2$
$W_1$ is weight of sample before experimenting
$W_2$ is weight of sample after experimenting
t = time (20min)
n =Rotational speed (510rpm)
r = is radius from center of sample (7cm)
By using the equation the results of nine samples that were coated and the original rod without coating were obtained. Where Table (4) lists these results.

**Table (4) Wear rate for alternative material**

| Test no. | Wear rate (g/cm) |
|---|---|
| **1** | $1.7832*10^{-7}$ |
| **2** | $8.9162*10^{-8}$ |
| **3** | $2.0061*10^{-7}$ |
| **4** | $2.0061*10^{-7}$ |
| **5** | $1.1145*10^{-7}$ |
| **6** | $4.4581*10^{-8}$ |
| **7** | $6.6871*10^{-8}$ |
| **8** | $6.6871*10^{-8}$ |
| **9** | $4.0123*10^{-7}$ |

We can see the wear rate value for rod without coating = $1.5157 *10^{-6}$

**Results and Discussions:**

Minitab software used to analysis the results. Depending on the results in table (4) the S/N ratio can be determined. The S/N ratio for the smaller has better quality characteristic used in this study and is calculated by equation (1):The results illustrated in table (5)

**Table (5) S/N ratio for experimental trials**

| Trial no. | S/N |
|---|---|
| 1 | 14.9760 |
| 2 | 20.9964 |
| 3 | 13.9529 |
| 4 | 13.9529 |
| 5 | 19.0584 |
| 6 | 27.0170 |
| 7 | 23.4952 |
| 8 | 23.4952 |
| 9 | 7.9321 |

After the S/N is obtained the average performance of each factor is calculated at each level and table (6) shows the result of that. Plot the average S/N value of each factor. Fig. (4) illustrates these results.

**Table (6) Average S/N table for factors**

| Factors | Average S/N at level 1db | Average S/N at level 2db | Average S/N at level 3db |
|---|---|---|---|
| Time[min] | 16.64 | 20.01 | 18.31 |
| Current[A] | 17.47 | 21.18 | 16.30 |
| Temp [ $c^o$] | 21.83 | 14.29 | 18.84 |

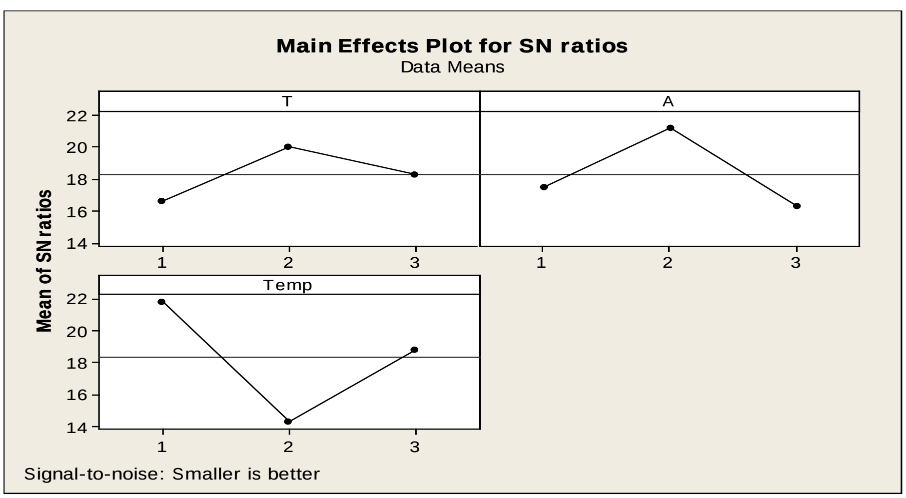


**Figure (4) Main effects plot for S/N ratios**

Using Minitab software ANOVA for S/N can be computed for all factors. By depending on the information of the ANOVA table the percentage contributions of the factors can be computed. Table (7) shows the ANOVA of S/N for all factors. Compute the percentage contributions for factors to explain the significance of factor affected in S/N. Fig (5) shows the percentage contribution of the factors.

**Table (7) ANOVA for S/N**

| Source of variation | DOF | Sum of squares | Mean squares | F-ratio | P% |
|---|---|---|---|---|---|
| Time | 2 | 17.01 | 8.506 | 0.11 | 5.78 |
| Current | 2 | 38.97 | 19.486 | 0.26 | 13.25 |
| Temperature | 2 | 86.38 | 43.188 | 0.57 | 29.36 |
| Residual Error | 2 | 151.78 | 75.892 | * | 51.6 |
| Total | 8 | 294.14 | | | |

Where:
mean squares = sum of squares / DOF and F- ratio = mean squares of factor / mean squares for error. P% = sum of squares of factor /total sum of squares

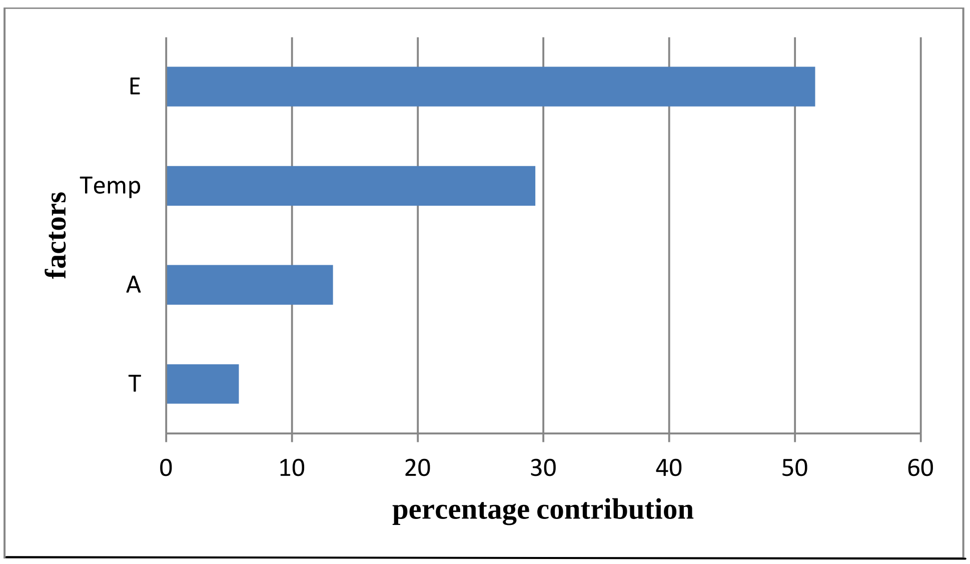


**Figure (5) Percentage contribution of S/N**

By depending on the information in Table (7) and Fig.(4) Temp(Temperature ) can be obtained that is the most significant factor that affects the S/N followed by A (Current ) and T (Time ). Before selections the level for each factor by using Fig.(3) the optimal levels for the factors that can increase the S/N are found they are:

1 The temperature at first level
2 The current at second level
3 The time at second level

The thickness of coating layer in the optimal level is 25µm.

## CONCLUSIONS:

1.CK50 steel coated by hard chromium gives high resistance to abrasive wear and high service life.

2.For the experimental design of coating process was applied Taguchi approach. Uses a special design of orthogonal arrays, only nine experiments were needed to determine the optimum condition for the Cr- electroplatingprocess.

3.The optimal levels by applying Taguchi method in coating process to increase the resistance of wear are: The temperature at first level is (45C$^{o}$) the current at second level (30 A) and the time at second level (20 min).

4.The temperature of electroplating process is the dominant parameter for wear test followed by current and time. The researcher recommend for a better result, a wider range of levels and more parameters should be used for Cr- electroplatingor coating processand application of other optimization techniques and comparing results obtained with Taguchi method.

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