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Research on experimental method of polishing copper alloy using magnetic abrasive polishing

Nguyen Duc Cuong[1], Nguyen Hong Tien[1], Le Van Nghia[1], Tran Anh Son[1]
[1]Faculty of Mechanical Engineering, Hanoi University of Industry, 298 Cau Dien street, Bac Tu Liem District, Hanoi, Vietnam

Abstract:
In recent years, the demands on the surface quality of products have been very high and surface polishing has been required to be performed on a wide range of materials with different hardnesses and complex geometries. In the past, metal was mainly polished by hand. From the difficulties and requirements of that product, several new surface polishing technologies have been developed. Among them, Magnetic Abrasive Polishing (MAP) and Magnetic Abrasive Finishing (MAF) have been developed and applied in the production process. Magnetic Abrasive Polishing (MAP) has been researched and developed to deal with the disadvantages of older methods. In this article, I only focus on studying the MAP process using spherical metal particles, the magnetic force is a permanent magnet. The implementation of this topic helps to build a theoretical basis and give experimental results in polishing the surface of copper alloy. Since then, it serves as a premise for the deployment and application of new technologies, applying science and technology to production in order to reduce labor time, reduce costs as well as increase productivity and quality.
***Key Word**: Surface polishing; copper; copper alloy; Cu; experimental; magnetic field*

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I. Introduction

Metal polishing is an important step in finishing metal surfaces, especially machine elements. The metal polishing process is performed by using external agents acting on the metal surface in order to create a product surface in accordance with the product's quality goals. [1]

Polishing tools are circular-motion polishing pads or abrasive polishing belts. The workpiece is pushed close to the surface of the polishing tool and receives the appropriate movements so that the work surface is polished [2]

Magnetic Abrasive Polishing (MAP) has been researched and developed to address the disadvantages of older methods. MAP is a new super-finishing technique used primarily to achieve nanometer-threshold surface accuracy especially for hard and non-magnetic materials such as stainless steel and ceramics.

MAP is a polishing technique that uses a permanent magnet or an electromagnet to generate a magnetic field in which a magnetic abrasive is formed as a flexible magnetic brush for polishing and finishing workpieces. The friction force generated by this finishing technique can also remove chips from the workpiece surface. The procedure is repeated until the desired accuracy of the surface is achieved.

MAP is a precision polishing method that can be used to achieve effective surface quality. The capability of removing material can be adjusted based on the size of the magnetic abrasive particles.

In the MAP process, the workpiece is held in the working gap between the north and south poles, the inductor is filled with abrasive grain powder. After this process, a better surface is produced without any effect on the surface of the workpiece. MAP methods have been effectively applied for polishing a wide variety of materials and different shapes of workpieces [4] and for polishing complex curved surfaces [5, 6]. The test setup is designed to generate unit vibrating finishing which consists of four permanent magnets in the tube axis direction. The combination of unit vibrating finishing and tube rotation for the mixture of pigments and abrasives as well as the relative motion of the mixture and the inner surface of the tube enhances the surface finishing efficiency.

Magnetic Abrasive Polishing method is effective for many different materials with advantages such as small force on the workpiece, no effect, no deformation for thin and small parts, reducing surface-treatment time, improving labor productivity.

II. Calculation Basis

2.1 Theory basis

Magnetic Abrasive Polishing involves filling the gap between the magnetic pole and the workpiece with the abrasive. Magnetic abrasives include pure iron powder (99.9% Fe) and Al2O3… The end face of the magnetic pole absorbs the magnetic abrasive and forms a closed magnetic field. The abrasive process is generated in a non-uniform magnetic field in which the abrasives engage and move in the direction of the magnetic force forming a flexible magnetic brush. Magnetic force is generated by permanent magnet to generate grinding force. The magnetic brush uses abrasive metal particles as a tool for finishing the surface of the workpieces. The magnetic pole rotates and moves relatively to the workpiece, the friction force generated by the MAP process makes the abrasives polish uneven surface until the surface becomes smoother. The magnetic brushes continue to move until the desired surface is reached, the magnetic field distribution is flat in the work area and the magnetic force (F) acts on the ferromagnetic particle [11]. During the MAP process, the magnetic abrasives are filled in the work area where the internal magnetic field is stronger than the external one [13]. Therefore, a non-uniform concentrated magnetic field distribution is formed between the magnetic pole and the workpiece holder. Magnetic force (F) is applied to the magnetic abrasives at position "i" located outside the work area to concentrate and pack them towards the work area. The magnetic force (F) acting on an abrasive can be expressed by equation (1).

$$F = V_0.B.\nabla B/\mu \qquad (1)$$

Where B and ∇B are the magnetic induction and its slope in the point "i" of a volume in the working area ; µ is the magnetic permeability.

When the magnetic permeability of grinding is greater than that of vacuum (µ> µ0), the magnetic force in equation (1) can be represented as a two-dimensional magnetic field distribution given in equations (2), (3).

$$F_x = V_0.X_m.\mu_0.H.\frac{\partial H}{\partial x} \qquad (2)$$

$$F_y = V_0.X_m.\mu_0.H.\frac{\partial H}{\partial y} \qquad (3)$$

Where: Fx is the component of the magnetic force in the x direction; Fy is the component of the magnetic force in the y direction; V_o is the volume of the magnetic particle; Xm is the magnetic susceptibility of the particle; µ0 is the vacuum permeability; H is the magnetic field strength at point "i"; (∂H /∂x) and (∂H / ∂y) are the density of the magnetic field in the x and y directions, respectively.

From equation (2), the magnetic force Fx and Fy are proportional to the mass of the magnetic abrasive, the magnetic permeability of the abrasive, and its magnetic field strength. The magnetic forces Fx and Fy are also capable of preventing the ejection of the abrasives due to the rotational speed of the wheel. During finishing, the magnetic field concentrates the abrasives to form a magnetic brush along the magnetic field line in the work area, exerting a pressure P on the flat surface and this pressure is applied to the work surface. Equation (4) represents the pressure, P, as follows:

$$P= \left[\mu_0 H^2 \left(1 - \frac{1}{\mu_m}\right)\right]/2 \qquad (4)$$

Where µm is magnetic permeability of abrasives;

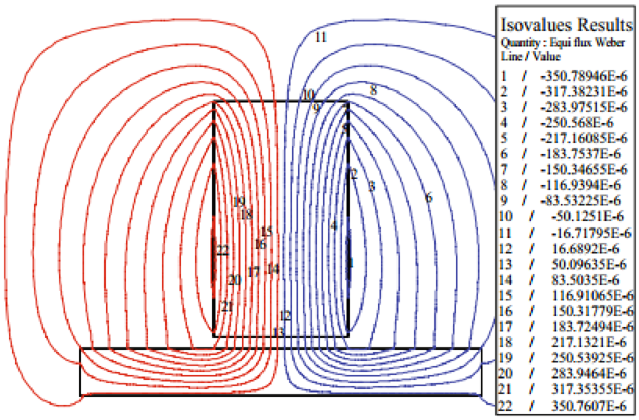

Figure 1: Magnitude values of magnetic field lines [12]

The particles on the work surface can be completed when the magnetic pole absorbs the magnetic abrasive to rotate and move simultaneously with the workpiece. Thus, a finished surface can be achieved. From equation (3), P represents the magnetic pressure pressed on the workpiece surface, as the magnetic pressure increases, the material removal rate increases. This also creates a great depth of finish and directly affects the surface quality. At the same time, the cutting force produced by grinding and the centrifugal force is a rotating magnetic pole and their result will remove the chip from the work area. However, abrasive ejection can be prevented when a high magnetic field is applied and the surface can be treated smoothly.

MAP uses permanent magnets to generate magnetic force as shown in figure (2.1). This leads to the formation of a closed-loop magnetic field due to the interaction of the permanent magnet, the magnetic abrasives, and the workpiece. The magnetic poles consist of a material with strong magnetism (Nd-Fe-B).

2.2. Effect of parameters on surface quality of the workpiece

a. Effect of abrasive grain size

The diameter of the magnetic abrasive grain affects the surface roughness. The higher the diameter of the magnetic abrasive particles is, the lower the surface roughness is. On the other hand, grains with smaller diameter will tend to increase the movement of the grains during polishing, thus resulting in less stable performance and less finished product. This indicates that there may be an interaction between the size of the magnetic abrasive grain and the speed.

b. Effect of polishing time

Polishing time also significantly affects surface roughness. However, the longer the polishing time is, the more the surface roughness changes. Surface roughness decreases rapidly during the initial polishing period and decreases slowly after a period of polishing. This may be the result of forces acting on the magnetic abrasive grains. Therefore, the longer the polishing time is, the less material is removed. This helps the workpiece to reach a glossy state.

c. Effect of working clearance

The working clearance also significantly affects the surface roughness. The larger the clearance is, the greater the surface roughness is, because the large working clearance affects the magnetic force of the magnet, which makes the magnetic field weak. Conversely, the smaller the clearance is, the smaller the surface roughness is. So the working clearance also significantly affects the polishing because it affects the magnetic force: The larger the clearance is, the weaker the magnetic force is; the smaller the clearance is, the greater the magnetic force is.

d. Effect of spindle speed

The spindle speed also significantly affects the surface roughness of the workpiece. Faster spindle speed results in faster cutting speed, making the surface roughness lower. This can be explained by the fact that at faster speed, the abrasive grains are prevented from entering the machinng area. The abrasive grains have not had time to create the cutting motion yet and has been pushed out.

e. Effect of other factors

It can be seen that the effect of other factors such as cutting speed, initial surface roughness, abrasive density, abrasive composition, jig, workpiece composition, etc. on surface roughness after polishing by MAP method is present. However, within this research, they are considered insignificant.

2.3. Design method of Taguchi experiment and calculation basis

Taguchi Design provides a powerful and efficient method for designing products that perform consistently and optimally under a variety of conditions.

In robust parametric design, the main goal is to find settings factor to minimize feedback bias, while adjusting (or keeping) the process on target. The robust parametric design is particularly suitable for energy-transfer processes, control proportional of coefficients and reciprocal reactions if possible. When interactions between control factors are likely to occur or not, a design that is capable of estimating such interactions should be chosen. Minitab can help choose a Taguchi design that doesn't cause confusion between mutual interactions or with main effects.

A Taguchi design, or an orthogonal array, is a method of designing experiments that typically require only a fraction of the full factor combinations. An orthogonal array means the design is balanced so that the coefficient levels are equally balanced. Because of this, each factor can be evaluated independently of all the others, therefore, the impact of one factor does not affect the evaluation of another.

In powerful parametric design, first, select the control elements and their levels and choose an appropriate orthogonal array for these control elements. The control elements include the inner array. Also, identify a set of confounding factors, along with designing experiments for this set of factors. Confounding factors include the outer array.

Taguchi's Loss function

The goal of the Taguchi method is to reduce costs for the manufacturer and the society by a change in the production process. Taguchi defined the difference between the target value of the efficiency characteristics of a process, τ, and the measured value, y, as a Loss function as in the formula.

$$l(y)= k_c(y-\tau)^2 \quad (5)$$

The constant, k_c, in the Loss function can be determined by considering the specification limits or the acceptable time interval, delta.

$$k_c = \frac{C}{\Delta^2} \quad (6)$$

It is difficult to determine what k_c is, τ and C are sometimes difficult to determine.

If the goal is to minimize the efficiency characteristic value, the Loss function is defined:

$$l(y)=k_c y^2 \qquad \text{với } \tau=0 \quad (7)$$

The Loss function described here is the loss to a customer from a product. By computing these loss functions, the overall loss to society can also be calculated.

Determine Design Arogalal Array parameter

The effect of various parameters on efficiency characteristics in a set of concise experiments can be tested by using the orthogonal array design proposed by Taguchi. Once the parameters affecting a controllable process have been determined, the extent to which these parameters have to be changed must be determined. Determining the level of a variable for testing requires an in-depth understanding of the process, including the minimum, maximum and current values of the parameters. If the difference between the minimum and maximum values of a parameter is large, the values that are tested can be separated further or more values can be tested.

Knowing the number of parameters and the number of levels, it is possible to choose the appropriate orthogonal array. Using table 2.4 to select array, the name of the appropriate array can be found by looking at the column and row corresponding to the number of parameters and the number of levels. Once the name has been determined (the index represents the number of trials that must be completed), the predefined array can be looked up. The links provided for many predefined arrays are given in the array selector. These arrays are created by the Taguchi algorithm which develop and allow each variable and set to be tested equally. If we have three parameters (voltage, temperature, pressure) and two levels (high, low), it can be seen that the appropriate array is L4. Click on the L4 link to view the L4 array, we can see four different experiments given in the array. The specified levels 1, 2, 3, etc. must be replaced in the array with the actual level values being changed, and P1, P2, P3 must be replaced by the actual parameters). The following links are connected to the image of the orthogonal array named in the link header [19]:

Table 1. Taguchi L4 Orthogonal Array

Trial	P1	P2	P3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Table 2. Taguchi L8 Orthogonal Array

Trial	P1	P2	P3	P4	P5	P6	P7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

Table 3. Select orthogonal arrays by parameter

		Số lượng tham số																													
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Số mức	2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
	3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L36	L36	L36	L36	L36	L36	L36	L36	L36	L36	L36								
	4	L16	L16	L16	L16	L32	L32	L32	L32	L32																					
	5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50																			

Table 4. Taguchi L9 Orthogonal Array

Trial	P1	P2	P3	P4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 5. Taguchi L12 Orthogonal Array

Trial	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	2	2	2	2	2	2
3	1	1	2	2	2	1	1	1	2	2	2
4	1	2	1	2	2	1	2	2	1	1	1
5	1	2	2	1	2	2	1	2	1	2	1
6	1	2	2	1	2	2	1	2	1	2	1
7	1	2	2	2	1	2	2	1	2	1	1
8	2	1	2	1	2	2	2	1	1	1	2
9	2	1	1	2	2	2	1	2	2	1	1
10	2	2	2	1	1	1	1	2	2	1	2
11	2	2	1	2	1	2	1	1	1	2	2
12	2	2	1	1	2	1	2	1	2	2	1

Table 6. Taguchi L16 Orthogonal Array

Trial	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
6	1	2	2	1	1	2	2	2	2	2	1	12	2	1	1
7	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1
11	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1

If the array which is selected based on the number of parameters and the level includes more parameters than used in the experimental design, ignore the additional parameter columns. (If a process has 8 parameters with 2 levels, each L12 array will be selected according to the array selector. As can be seen below, the L12 array as shown in table 5 has columns for 11 parameters (P1-P11). 3 columns to the right are ignored).

Table 7. Multi-parameters orthogonal arrays

Trial	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	2	2	2	2	2	2
3	1	1	2	2	2	1	1	1	2	2	2
4	1	2	1	2	2	1	2	2	1	1	1
5	1	2	2	1	2	2	1	2	1	2	1
6	1	2	2	1	2	2	1	2	1	2	1
7	1	2	2	2	1	2	2	1	2	1	1
8	2	1	2	1	2	2	2	1	1	1	2
9	2	1	1	2	2	2	1	2	2	1	1
10	2	2	2	1	1	1	1	2	2	1	2
11	2	2	1	2	1	2	1	1	1	2	2
12	2	2	1	1	2	1	2	1	2	2	1

Analyze experimental data

Once the experimetal design has been determined and the experiments have been performed, the efficiency characteristics measured from each experiment can be used to analyze the relative effectiveness of different parameters. To demonstrate the data analysis procedure, the following L9 array will be used, but the principles can be converted to any type of array.

In this array, it can be seen that any number of repeated (experiments) observations can be used. Ti, j represent different trials with i = number of trials and j = number of experimental factors. It should be noted that the Taguchi method allows the use of a confounding matrix that includes external factors affecting process results rather than repeated experiments, but this is beyond the range of this article.

To determine the effect each variable has on the output, the signal-to-noise ratio, or number of SNs, needs to be calculated for each performed experiment. The SN calculation for the first test in the above array is shown below for the specific target value of the efficiency characteristics. In the equations below (8), (9), (10), yi is the mean and si is the variance. yi is the value of the efficiency characteristics for a given experiment [19].

$$SN_i = 10log\frac{y}{s_i^2} \tag{8}$$

where

$$y_i = \frac{1}{N_i}\sum_{u=1}^{N_i} y_i, u \tag{9}$$

$$S_i^2 = \frac{1}{N_i-1}\sum_{u=1}^{N_i}(y_{i,u} - y_i)$$

I = Number of experiments; U = Experimental times; Ni= Number of trials of i experiment

For the case of minimizing the efficiency characteristics, the definition of SN should be determined according to formula (10):

$$SN_i = -10\log\left(\sum_{u=1}^{N_i}\frac{y_u^2}{N_i}\right) \tag{10}$$

For the case of maximizing the efficiency characteristics, the definition of SN should be determined according to formula (11):

$$SN_i = -10\log\left[\frac{1}{N_i}\sum_{u=1}^{N_i}\frac{1}{y_u^2}\right] \tag{11}$$

After calculating the SN ratio for each trial, the mean SN value is calculated for each factor and level according to formulas (12), (13), (14). This is performed as shown below for parameter 3 (P3) in the array:

Table 8. S/N Ratio

Trial	P1	P2	P3	P4	S_N
1	1	1	1	1	S_{N1}
2	1	2	2	2	S_{N2}
3	1	3	3	3	S_{N3}
4	2	1	2	3	S_{N4}
5	2	2	3	1	S_{N5}
6	2	3	1	2	S_{N6}
7	3	1	3	2	S_{N7}
8	3	2	1	3	S_{N8}
9	3	3	2	1	S_{N9}

$$SN_{P3.1} = \frac{(S_{N1} + S_{N6} + S_{N8})}{3} \tag{12}$$

$$SN_{P3.2} = \frac{(S_{N2} + S_{N4} + S_{N9})}{3} \quad (13)$$

$$SN_{P3.1} = \frac{(S_{N3} + S_{N5} + S_{N7})}{3} \quad (14)$$

Once these SN values are calculated for each factor and level, they are tabulated as shown below and the Delta range (Delta = high SN - low SN) of the SN for each parameter is calculated and entered into the Table. 9. The larger the R value for a parameter, the greater the variable effect in the process. This is because the same change in signal causes a larger effect on the measured output variables.

Table 9. Delta Value

Level	P1	P2	P3	P4
1	$SN_{P1,1}$	$SN_{P2,1}$	$SN_{P3,1}$	$SN_{P4,1}$
2	$SN_{P1,2}$	$SN_{P2,2}$	$SN_{P3,2}$	$SN_{P4,2}$
3	$SN_{P1,3}$	$SN_{P2,3}$	$SN_{P3,3}$	$SN_{P4,3}$
Δ	R_{P1}	R_{P2}	R_{P3}	R_{P4}
Rank	…	…	…	…

The advantage of the Taguchi method is that it emphasizes the mean efficiency characteristics value closer to the target value rather than the value within a certain specification limit, thus improving product quality. Besides, Taguchi method is simple and easy to apply to many technical situations, making it a powerful yet simple tool. It can be used to quickly narrow the rage of a research project or to identify problems in a production process from existing data. In addition, the Taguchi method allows analysing many different parameters without a high number of trials. By this way, it is possible to determine the main parameters that have the most influence on the efficiency characteristics value so that the experiment can be performed to obtain results:

- The operating principle of Magnetic Abrasive Polishing (MAP) method has been proposed.
- Researching the parameters: working clearance, abrasive grain diameter, polishing time and spindle speed have a significant influence on surface roughness when using Magnetic Abrasive Polishing method.
- Studying the Taguchi Experimental Design model to determine the factors affecting the surface roughness when polishing. From there, select the appropriate experimental method for the topic.

III. Experimental Results And Data Processing

3.1. Experimental results

The schematic diagram of the experiment is set up in figure 2 and the working conditions are listed in table 10. In this experiment, the copper workpiece is fixed on a non-magnetic aluminum alloy before the assembly was mounted on the spindle of milling machine. The workpiece rotates in a circular motion while the grinding wheel rotates at the speed of the jig motor and experiences the translational motion along the table. All selected experimental factors are changed with three levels described in table 11. Apply Taguchi method when using L9 orthogonal array (34) consisting of four parameters and three levels described in Table 11.

In order to obtain more accurate experiment results, after cleaning the workpiece, measure the surface roughness.

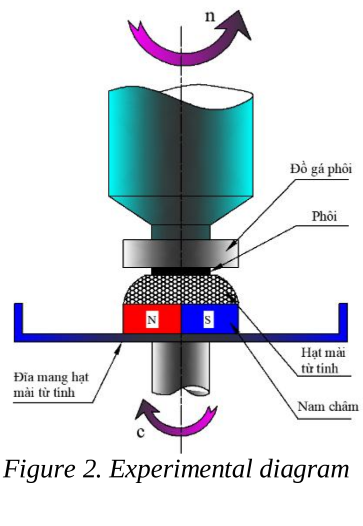

Figure 2. Experimental diagram

Table 10. Experimental conditions

Data	Condition
Sphere abrasive (d)	Dimensions 0.4 mm; 0.8 mm; 1.2 mm
Processing machine	Hitachi Seiki milling machine
Polishing time (t)	Minutes
Permanent magnets	NdFeB
Polishing material	Copper

Table 11. Factors and levels in the experiment

Factor	Level		
	1	2	3
Spindle speed (rpm)	300	550	700
Particle size (mm)	0.4	0.8	1.2
Polishing time t (min)	20	40	60
Working clearance (mm)	6	8	10

3.2. Analyze experimental results

The main factors affecting the surface roughness of the workpiece after machining: rotation speed of the workpiece, machining time, abrasive grain size, working clearance. In addition to these factors, the quality of the workpiece surface is also influenced by other factors such as: material, structure, jig, machine type, ... These other factors are considered as confounding factors in the topic, do not affect the workpiece surface much.

Table 12. Roughness measurement results

Ordinal numbers of workpiece	**BLOCK**	**Abrasive grain size**	**Working clearance**	**Polishing time**	**Spindle speed**	**Ra before experiment**	**Ra after experiment**
		mm	mm	min	rpm	Un	Un
1	1	0.4	10	20	350	0.73	0.55
2	1	0.8	10	60	525	0.8	0.25
3	1	0.4	6	60	525	0.68	0.26
4	1	0.4	6	20	700	0.77	0.47
5	1	0.8	6	40	525	0.9	0.14
6	1	1.2	8	60	350	0.68	0.25
7	1	1.2	10	60	700	0.84	0.15
8	1	0.8	8	40	525	0.64	0.04
9	1	0.8	6	40	700	0.89	0.14
10	1	0.4	8	60	525	0.95	0.13
11	1	1.2	10	60	525	0.79	0.17
12	1	0.4	8	60	700	0.95	0.11
13	1	0.4	8	20	700	0.71	0.25
14	1	0.8	10	40	350	0.91	0.34
15	1	0.8	6	40	350	0.57	0.14
16	1	0.8	8	60	350	0.65	0.18
17	1	0.4	6	40	525	0.82	0.22
18	1	1.2	10	40	700	0.83	0.2
19	1	0.4	6	40	350	0.69	0.29
20	1	0.4	8	60	350	0.78	0.17
21	1	1.2	8	60	525	0.78	0.23
22	1	1.2	8	40	525	0.73	0.22
23	1	0.8	10	60	350	0.84	0.29
24	1	0.8	10	60	700	0.96	0.21
25	1	0.4	10	40	350	0.73	0.31
26	1	0.8	8	20	525	0.79	0.2
27	1	0.4	10	60	350	0.75	0.22
28	1	0.4	6	40	700	0.87	0.27
29	1	0.4	8	40	525	0.94	0.18
30	1	0.8	8	60	525	0.9	0.08
31	1	0.8	10	20	700	0.96	0.37
32	1	1.2	10	20	525	0.77	0.36
33	1	0.4	8	40	350	0.72	0.25
34	1	0.8	8	20	350	0.62	0.28
35	1	1.2	10	40	350	0.93	0.47
36	1	1.2	8	40	350	0.79	0.47
37	1	0.4	10	20	700	1.25	0.37
38	1	0.8	6	60	350	0.73	0.11
39	1	0.4	10	20	525	0.8	0.34
40	1	1.2	10	20	700	0.66	0.38

41	1	0.8	6	20	350	0.73	0.26
42	1	0.8	6	60	700	0.7	0.12
43	1	0.4	10	60	525	0.65	0.23
44	1	0.4	6	60	700	0.64	0.29
45	1	0.4	6	60	350	0.7	0.4
46	1	1.2	6	20	700	0.89	0.21
47	1	0.4	8	40	700	0.83	0.12
48	1	1.2	8	40	700	0.74	0.24
49	1	0.8	8	20	700	0.62	0.19
50	1	0.8	6	20	525	0.89	0.2
51	1	1.2	6	40	350	0.83	0.26
52	1	1.2	6	20	525	0.81	0.3
53	1	1.2	6	40	700	0.72	0.14
54	1	0.4	10	40	700	0.98	0.27
55	1	1.2	6	20	350	78	0.33
56	1	0.8	10	40	700	0.81	0.32
57	1	0.8	8	40	700	0.86	0.15
58	1	1.2	10	40	525	0.73	0.19
59	1	1.2	8	20	525	0.88	0.33
60	1	1.2	8	20	700	0.87	0.24
61	1	0.8	10	40	525	0.75	0.37
62	1	1.2	10	60	350	0.93	0.42
63	1	0.8	6	60	525	0.78	0.09
64	1	1.2	6	60	700	0.98	0.12
65	1	1.2	8	20	350	0.87	0.32
66	1	0.8	8	40	350	0.63	0.22
67	1	1.2	6	60	525	0.96	0.15
68	1	0.4	6	20	525	0.93	0.36
69	1	1.2	8	60	700	0.64	0.16
70	1	0.4	10	40	525	0.7	0.15
71	1	1.2	6	40	525	0.75	0.15
72	1	0.4	10	60	700	0.5	0.13
73	1	0.4	8	20	525	0.67	0.39
74	1	0.8	10	20	525	0.91	0.31
75	1	0.8	10	20	350	0.99	0.41
76	1	0.4	8	20	350	0.81	0.38
77	1	0.8	6	20	700	0.81	0.28
78	1	0.4	6	20	350	0.8	0.3
79	1	0.8	8	60	700	0.68	0.21
80	1	1.2	10	20	350	0.8	0.41
81	1	1.2	6	60	350	0.75	0.17

Select orthogonal tables and design experimental matrix.

Table 13. Orthogonal tables L9 (3^4)

Trial	Abrasive grain size	Working clearance	Machining time	Spindle speed
	mm	mm	min	rpm
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Data Analysis: Using orthogonal tables L9(3^4)

Table 14. Roughness measurement results

Workpiece	Abrasive grain size	Working clearance	Machining time	Spindle speed	Ra trial 1	Ra trial 2	Ra mean	Mean square
	mm	mm	min	rpm	Um	Um	Um	Um
1	0.4	6	20	350	0.3	0.32	0.31	0.0961
2	0.4	8	40	525	0.18	0.23	0.205	0.0420
3	0.4	10	60	700	0.13	0.15	0.14	0.0196
4	0.8	6	40	700	0.14	0.12	0.13	0.0169
5	0.8	8	60	350	0.18	0.13	0.155	0.0240

6	0.8	10	20	525	0.31	0.37	0.34	0.1156
7	1.2	6	60	525	0.15	0.18	0.165	0.0272
8	1.2	8	20	700	0.24	0.22	0.23	0.0529
9	1.2	10	40	350	0.47	0.4	0.435	0.1892

The effect of this factor is determined by determining the difference

Δ= Max- Min= 21.2789-17.38= 3.8989

Similar to the remaining values, we can obtain the following table:

Table 15. Effect of factors

Level	**Abrasive grain size d(mm)**	**Working clearance s(mm)**	**Spindle speed n(rpm)**	**Machining time t(min)**
1	0.052575	21.27891	0.103117	0.0882
2	0.052175	17.38	0.061617	0.082717
3	0.089783	18.92762	0.0298	0.023617
Δ	**0.037608**	**3.898906**	**0.073317**	**0.064583**
Rank	4	1	2	3

The S/N ratio was used to evaluate the variability of the Taguchi method. The larger the S/N ratio is, the more affected the surface roughness of the workpiece after the MAP method is. The calculation of the difference of S/N ratio calculated in table 3.10 is determined by the value of the roughness after polishing. In the Taguchi method, the highest value of S/N represents the main influence on surface roughness Ra. We see that the working clearance s (mm) is the factor that has the greatest influence on the surface roughness Ra of the workpiece, the next influencing factors are the spindle speed n (rpm), machining time t (min) and abrasive grain size d (mm) [19]

Table 16. Prediction results of surface roughness Ra (Un)

Factor	**Result**	**Confidence interval Int.**	**VIF**
Mean	0,154815	+/- 0,0437064	
A: Abrasive grain size	-0.0137037	+/- 0,0356861	1
B: working clearance	0,0748148	+/- 0,0356861	1
C: machining time	-0,135556	+/- 0,0356861	1
D: spindle speed	-0.0837037	+/- 0,0356861	1
AA	0,0981481	+/- 0,0618102	1
AB	0,0672222	+/- 0,0437064	1
AC	0,0227778	+/- 0,0437064	1
AD	-0.0372222	+/- 0,0437064	1
BB	0,0881481	+/- 0,0618102	1
BC	-0.0238889	+/- 0,0437064	1
BD	-0.0444444	+/- 0,0437064	1
CC	0,0392593	+/- 0,0618102	1
CD	-0.0222222	+/- 0,0437064	1
DD	0,0637037	+/- 0,0618102	1

95.0% confidence interval based on total errors with 66 df (t = 1.99657)

The analytical results as shown in Table 16 show the influence of factors affecting the quality of the work surface with the confidence interval of the estimation method being 95%. The analysis results give the largest variance inflation factor (VIF) equal to 1, showing that the orthogonal design process is optimal. Analytical parameters greater than 10 often show a high disorder among the factors and provide estimation information about surface roughness according to Ra from the proposed model. The results shown include: experimental parameters of surface roughness Ra, estimation parameters Ra and confidence interval limits for the estimation model [19].

Compare of factors affecting the quality of polished surface

With a 95.0% confidence interval for the mean of Ra:

0,251235 ± 0,0233759 [0,227859, 0,27461]

Table 17. Parameters of the best surface quality

Abrasive grain size d	**Working clearance s**	**Machining time t**	**Spindle speed n**	**Ra**
(mm)	(mm)	(min)	(rpm)	(Un)
0,8	**8,0**	**40,0**	**525,0**	**0,154815**
1.8	-8,75999	117,07	932,19	3,34806
2,8	50.5658	-50,6448	-600.469	32,1915
3,8	59.174	-63,775	-924.739	49.0706
4,8	67.2171	-74.6692	-1235,53	68.5952
5,8	74.8758	-84.0445	-1537.2	90.6869

Using Taguchi design software and Statgraphics data processing software, together with existing data in this experiment, the working clearance factor has the greatest influence on the surface roughness of the workpiece.

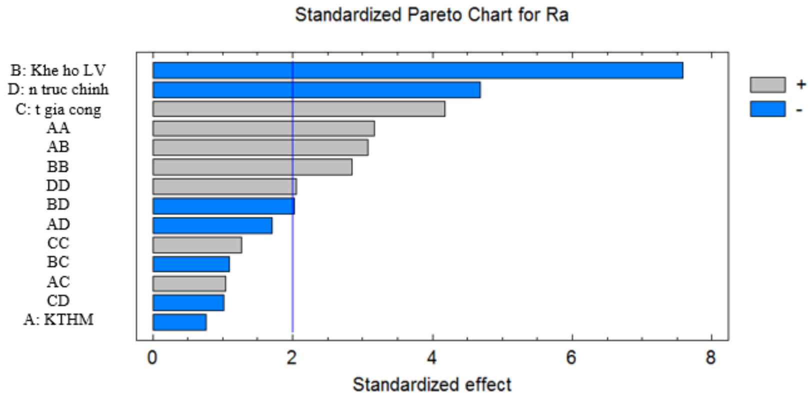

Figure 3. Effect of roughness on Ra

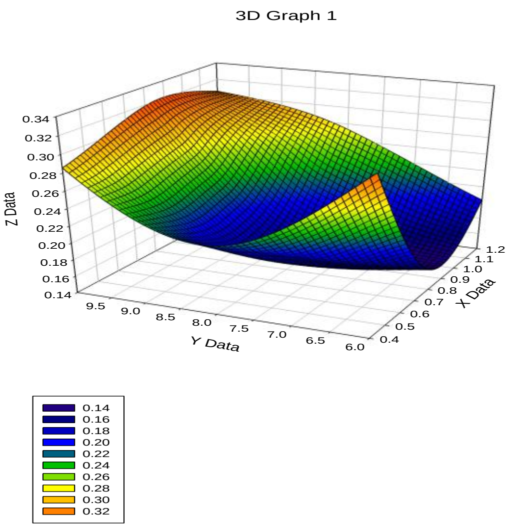

Figure 4. Effect of abrasive grain size and working clearance on Ra

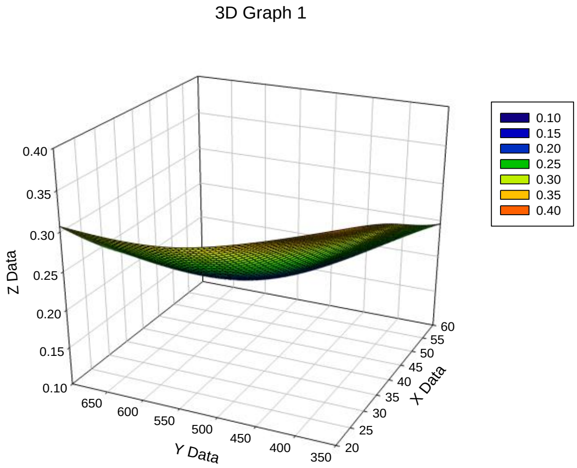

Figure 5. Effect of machining time and spindle speed on Ra

IV. Conclusion And Recommendations

4.1. Conclusion

- Systematize the theoretical basis of the traditional polishing technology and methods as well as the polishing methods being used in the world today. As well, an overview of the operating principle of the MAP method is introduced, the influence of technological factors on the quality of the surface after machining. Since then, the author has determined and selected the most important parameters in the experimental processes of polishing copper alloy with the following parameters: abrasive grain size (d), working clearance (s), machining time (t), spindle speed (n).

- In this study, by using the Taguchi experimental design method as well as the use of Statgraphics data processing software, the analysis and evaluation of experimental results ensures accurately the influence of the parameters. The research results show that the working clearance has the greatest influence on the surface roughness, then the influence of spindle speed, machining time, and finally the abrasive grain size has the smallest influence to the surface quality. Research has indicated that with parameters: d = 0.8 (mm), s = 8 (mm), t = 40 (min), n = 525 (rpm), we have the best surface after experiment with Ra= 0.04 µm.

- The experimental results of the research can be used as a scientific basis for the application of the MAP method in the study of polishing non-magnetic materials in mechanical processing.

4.2. Recommendations

In this research, the author has studied the individual interaction effects of the parameters on the surface roughness (abrasive grain size d, working clearance s, machining time t, spindle speed n) when machining on the surface of Copper material. This result is also a premise for developing further studies in the polishing field.

- Evaluating the interactive effects of different parameters on surface roughness for different materials.
- Researching the application of MAP method when machining workpiece with different sections.

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