OPTIMIZATION OF PLASMA SPRAYING PARAMETERS TO FRICTION PROPERTIES OF 60% AL_2O_3 – 40% TIO_2 COATINGS

TỐI ƯU HOÁ THÔNG SỐ PHUN PHỦ PLASMA ĐẾN ĐẶC TÍNH MA SÁT CỦA LỚP PHỦ 60% Al_2O_3 – 40% TiO_2

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ABSTRACT

In this research, the tribological properties of the Al_2O_3 - TiO_2 ceramic alloy plasma spraying on the surface of C45 carbon steel were investigated and optimized to improve the mechanical wear-resistance of the parts machine. The influence of spray mode parameters on the friction coefficient of the coating was evaluated using the Taguchi method and ANOVA technique. Survey and optimization results show that the coating has the smallest friction coefficient of 0.49 when using spray parameters of 600A spraying current and 2.1kg/hour powder feed flow during the spraying process. The spray distance is 130mm, and the spray current intensity has the most significant influence, with 80.1%, on the friction coefficient of the test samples. The obtained experimental results had an error of 4.08% compared to the optimal values.

Keywords: *Plasma praying layer; 60% Al_2O_3 – 40% TiO_2; Optimization; Coefficient.*

TÓM TẮT

Trong nghiên cứu này, các đặc tính ma sát học của lớp phủ plasma hợp kim gốm hệ Al_2O_3 - TiO_2 trên bề mặt thép các-bon C45 được khảo sát và tối ưu hoá nhằm nâng cao khả năng chống mài mòn cơ học của các chi tiết máy trong quá trình sử dụng. Ảnh hưởng của các thông số chế độ phun tới hệ số ma sát của lớp phủ được đánh giá bằng phương pháp Taguchi và kỹ thuật ANOVA. Các kết quả khảo sát và tối ưu cho thấy, lớp phủ có hệ số ma sát nhỏ nhất là 0,49 khi sử dụng bộ thông số phun là cường độ dòng điện phun 600A, lưu lượng cấp bột trong quá trình phun là 2,1kg/giờ, khoảng cách phun là 130mm và cường độ dòng điện phun có ảnh hưởng lớn nhất với 80,1% đến hệ số ma sát của các mẫu thử. Các kết quả thí nghiệm kiểm chứng thu được có sai số là 4,08% so với các giá trị tối ưu.

Từ khoá: *Lớp phủ plasma, Hệ gốm 60% Al_2O_3 – 40% TiO_2, Tối ưu hoá, Hệ số ma sát.*

1. INTRODUCTION

Thermal spraying has many advantages, including diverse spray materials that enable the coating quality to meet the harsh working conditions of machine parts. Mainly, it is cost-effective, leading to its widespread application in various industries such as infrastructure construction, biomedical, electronics, and more [1-4, 9]. The wear resistance capability depends on many factors, such as surface preparation, spray materials, and especially the spray technology parameters [5]. Plasma spraying, with its high thermal power, offers high productivity, various spray materials, and good coating quality [9].

The factors contributing to coating quality include the spray equipment, spray materials, and spray technology parameters, among which the spray technology parameters play a crucial role [5-12]. Ceramic coatings based on Al_2O_3 possess many good technical properties such as high hardness, wear resistance, chemical durability, and resistance to high temperatures [9]. Optimizing the spraying parameters to create a high-quality coating is essential. Therefore, researching the optimization of spraying parameters to reduce the friction coefficient of Al_2O_3 – 40%TiO_2 ceramic coatings is necessary. Experimental design according to the L9 array of TAGUCHI combined with ANOVA variance analysis is used to find the optimal parameter set for the friction coefficient of the coating [4, 7].

2. EXPERIMENTAL PROCEDURE

2.1. Substrate and Coating Materials

Substrate samples with 50 x 50 x 6 mm dimensions were roughened to a surface roughness of 8 to 10 µm. The roughening process was carried out using a TM-R-6F machine (Italy) at the Institute of Mechanical Research Laboratory, and the roughness was measured using a Mitutoyo 178-954-4E roughness tester (Japan). The sample spray material used was C45 steel.

Table 1. Chemical Composition of C45 Steel [7]

Grade			C45
Content (%)	C		0.42-0.50
	S		0.17 – 0.37
	Mn		0.50 – 0.80
	P	≤	0.04
	S		0.04
	Cr		0.25
	Ni		0.25

Metallization, UK supplied the Al_2O_3 – TiO_2 spray powder used for the plasma spraying method. The powder particles selected for experimental spraying ranged from 5 to 45±5 µm. The powder's composition includes 60% Al_2O_3 and 40% TiO_2, creating a coating that provides excellent wear resistance.

2.2. Experimental Spraying process

The spraying was carried out using the PRAXAIR Model 3710 plasma spraying system equipped with an SG100 spray gun to fabricate the ceramic coating. The coating thickness was maintained at 400 µm with a 10 to 20 µm deviation. The spray parameters were arranged according to Taguchi's L9 orthogonal array (Table 2). The remaining parameters are shown in Table 3.

Table 2. Research Parameters and Levels used in this study

Spray parameters	Symbol	Level		
		1	2	3
Powder feed rate (kg/h)	M	1.7	1.9	2.1
Spray distance (mm)	L	90	110	130
Current (A)	I	400	500	600

Table 3. Other spray parameters

Spray parameters		Giá trị
Spray gun movement speed (m/min)		20
Vontage (V)		60
Primary flow	(l/min)	120
Secondary air flow	(l/min)	15
Powder carrier gas flow	(l/min)	10

2.3. Testing Method

The testing phase was rigorously conducted, focusing on the coating's dry wear and sliding wear resistance from 60% Al_2O_3 – 40% TiO_2 spray powder using various abrasion methods [8]. These measurements were carried out at the esteemed Metallography and Heat Treatment Laboratory of Hanoi University of Science and Technology, known for its stringent quality standards. The friction coefficient was measured under dry conditions (without lubricant), with an applied load of 10 N, at room temperature.

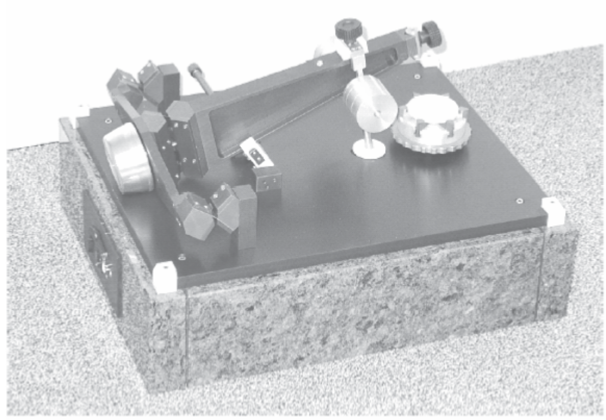


Figure 1. Friction Coefficient Measurement Device (Static Friction)

3. RESULTS AND DISCUSSION

3.1. Experimental Results

The spraying process parameters were designed according to Taguchi's L9 orthogonal array [4, 7]. After spraying, the coating samples were ground flat to achieve a uniform thickness of 0.4 mm and then cut into smaller pieces using the wire-cutting method. The size and number of the samples included ten pieces, with nine samples corresponding to the nine experiments and the 10th sample used for verification testing (Figure 2).

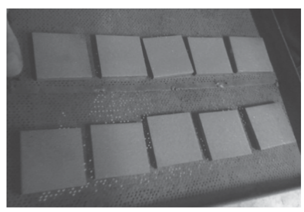


Figure 2. Image of the Samples After Spraying

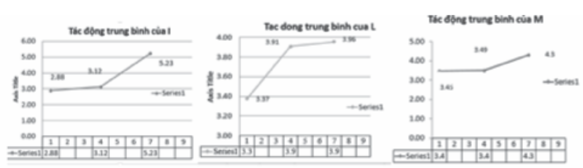


Figure 3. Impact Level Diagram of Parameters I, L, M

Table 4. Experimental Parameters According to L9 Array and Friction Coefficient measurement Results

No.	Spray parameters			Friction coefficient
	I	M	L	
1	400	1.7	90	0,757
2	400	1.9	110	0,709
3	400	2.1	130	0,688
4	500	1.7	110	0.786
5	500	1.9	130	0,628
6	500	2.1	90	0,689
7	600	1.7	130	0,524
8	600	1.9	90	0,582
9	600	2.1	110	0,538

The results from Table 5 indicate that the parameter level combination I3L3M1, corresponding to I = 600 A, L = 130 mm, and M = 1.7 kg/h, produces the coating with the lowest friction coefficient of 0.524. The variation in spray parameters significantly affects the measured values, demonstrating that the current intensity, powder feed rate, and spraying distance have a substantial impact on the coating's friction coefficient. This confirms that selecting these parameters for investigation is appropriate.

3.2. S/N Ratio Analysis

Reducing the friction coefficient of the coating helps improve its durability during operation, particularly for coatings subjected to wear [4]. Therefore, the S/N ratio, according to Taguchi's method, where smaller values are better, was used to calculate based on each experimental result using Minitab15 software and presented in Table 5. The optimal parameters are the levels of spray parameters with the highest average S/N ratio. Figure 4 illustrates the impact variation of factors influencing the friction coefficient of the coating, indicating that the predicted optimal spray parameter combination is I3L3M3 (I = 600 A, L = 130 mm, M = 2.1 kg/h). The predicted optimal results show a significant improvement in the friction coefficient of the coating.

To determine the influence of parameters (I, M, L) on coating adhesion, variance analysis based on experimental results and S/N values will be conducted. The calculation process will rely on Minitab software; the results are shown in Table 5.

Table 5. ANOVA Analysis Results Based on S/N Ratio

Parameters	Degrees of freedom	Sum of squares of factors	Mean squared	Influence level
I	2	0,053	0,026299	80,1%
L	2	0.005	0,0025	7,6%
M	2	0,008	0,004034	12,3%
Sum	8	0,066	--	100%

The influence percentage in Table 5 shows that spray current (I) has the largest influence on coating porosity, with 80.1%, powder feed rate (M) is 12.3%, and spray distance (L) is 7.6 %. The chart in Figure 5 illustrates this.

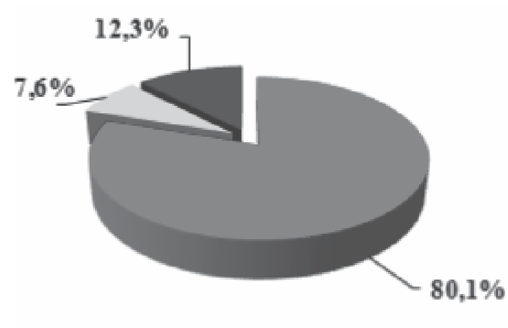


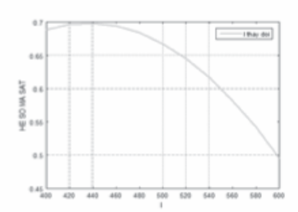
Figure 4. Percentage influence of parameters I, M, L on coating friction coefficient.

3.3. Evaluate the relationship between coating friction coefficient and spray parameters

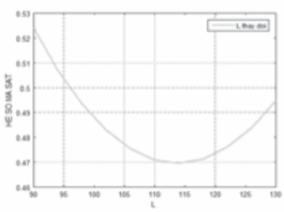
To analyze the influence trend of parameters I, M, and L on the coating friction coefficient (σbd), the regression function represents the mathematical relationship between σbd and spray parameters I, M, and L below. Linear form is constructed. Minitab software with the Gau-Newton algorithm obtains the mathematical function (1):

$$H = -7,6082.10^{-6}.I^2 + 9,6476.10^{-5}.L^2 - 0,7623.M^2 - 0,0012.I.M + 0,0051.L.M + 0,0092.I - 0,0327.L + 2,7972.M - 2,0411 \quad (1)$$

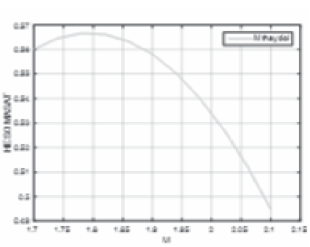
With $R^2 = 0.9864$, the mathematical function obtained is highly reliable as all R^2 values approach 1. The optimal spray parameters are determined to be I3L3M3. Combining this with the regression equation (1), the influence of each spray parameter on the friction coefficient of the coating can be determined through the graphs in Figures 5 and 6.



a, Effect of I

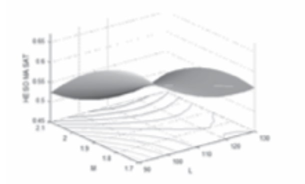


b. Effect of L

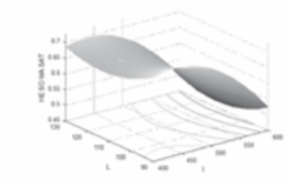


c. Effect of M

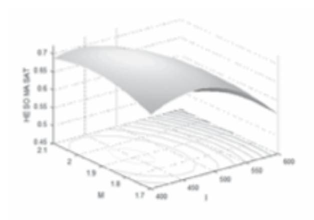
Figure 5. Graph of the dependence of friction coefficient on spray parameters at the optimal level in 2D form.



a. Influence of M and L;



b. Influence of L and I



c. Influence of M and I

Figure 6. Graph of the dependence of friction coefficient on spray parameters at the optimal level in 3D.

Figure 6a shows that when L and M vary, the friction coefficient reaches its minimum value at the point where L = 130 mm and M = 2.1 kg/h. Similarly, Figures 6b and 6c demonstrate the correlation between the friction coefficient and the spraying distance and current intensity, respectively.

3.4. Verification Experiment

A sample was sprayed with the optimal spray parameters I3L3M3, then cut and ground before measuring the coating's friction coefficient. The friction coefficient measured on the verification sample was 0.51, while the optimal criterion yielded a result of 0.49. The deviation was 4.08% compared to the optimal value. Although slightly higher than the optimal value, the obtained result is considerably lower than in Table 4.7.

4. CONCLUSIONS

In this study, the Taguchi method combined with ANOVA was used to optimize spray parameters, including current intensity (I), spraying distance (L), and powder feed rate (M), for the friction coefficient of Al_2O_3 – TiO_2 coating on C45 steel substrate using plasma spraying. The optimization process identified the optimal spray parameters (I = 600 A, L = 130 mm, M = 2.1 kg/h) for the coating with the lowest friction coefficient of 0.49. ANOVA analysis showed that the order of influence of parameters on the friction coefficient was current intensity (80.1%) > powder feed rate (12.3%) > spraying distance (7.6%). The verification experiment resulted in a friction coefficient of 0.51, slightly higher than the optimal value but lower than the experimental sample results (Table 4), with a deviation of 4.08% from the predicted result. This confirms the optimal parameters for a high-quality coating with a low friction coefficient. The combination of Taguchi-ANOVA methods proves to be an effective tool for optimizing problems with multiple influencing factors. ❖

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