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Optimization of Deposition Parameters for MPCVD Diamond Coatings Grown on WC-Co Substrates Using Taguchi and Analytic Hierarchy Process Method

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ABSTRACT

In this study, substrate temperature (t), total pressure (p), methane flow (M) and carbon dioxide flow (C) were considered to deposit diamond coatings on WC/Co (6wt.%) substrates under $\text{CH}_4/\text{H}_2/\text{CO}_2$ atmosphere. The Taguchi method and AHP method were used to determine the parameter plan and the sequence of the parameter plan, respectively. The results showed that three schemes with better parameters could be determined through the Taguchi method, the best parameters with $t=750\text{ }^\circ\text{C}$, $p=6\text{ kPa}$, $M=7\text{ mL/min}$, $C=4\text{ mL/min}$ could be chosen based on AHP analysis and the best parameters could be verified through experiment.

Keywords: Diamond coating; Parameters optimization; Taguchi method; AHP analysis.

1. INTRODUCTION

Diamond coatings are the most important industrial materials which have excellent properties such as chemical inertness, tribological performance, anti-corrosion performance, mechanical, extreme hardness and biocompatibility (Li et al. 2016; Shen et al. 2013; Ali et al. 2004). It is promising material for industrial applications including cutting tools, optical coatings and many other potential applications (Salgueiredo et al. 2013; Zhang et al. 2014). At present, the main materials of common tools, drills, molds and other materials are cemented carbide, and it is a more

important issue to improve their wear resistance and service life. However, the key problem of depositing diamond coating on cemented carbide substrate is that the bonding strength between the coating and the substrate is low and easy to fall off.

To obtain high-quality and excellent-performance coatings, parameter optimization by chemical vapor deposition (CVD) method is a research direction. [Zhang et al. \(2014\)](#); [Wang et al. \(2015\)](#); [Wei et al. \(2009\)](#) were to study deposition parameters of diamond coatings on WC/Co substrates and achieve a series of research results. An optimum selection of deposition parameters is extremely important. Traditionally, the study of influencing factors belongs to the single factor method. How to analyze the conditions of multi-factors, analyze their weight and importance ranking, some mathematical application methods were applied such as orthogonal experiment method, Taguchi method, harmonic response analysis, analytic hierarchy process, technique for order preference by similarity to an ideal solution and so on.

Due to prepare and obtain a better diamond coating surface quality, mathematical theory research is becoming more and more extensive. [Manivel and Gandhinathan \(2016\)](#) optimized cutting parameters for turning of austempered ductile iron based the Taguchi method. [Alberto et al. \(2014\)](#) used the Taguchi method with multiple performance characteristics in the optimization of optical fibres. [Jiang et al. \(2016\)](#) optimized the growth parameters of diamond films using Response Surface Methodology. [De Souza et al. \(2018\)](#) was based on AHP–TOPSIS-2N (Analytic Hierarchy Process-Technique for Order Preference by Similarity to Ideal Solution) method for decision-making on the multi-objectives of the project portfolio. [Zaidan et al. \(2020\)](#) recruited software programmers from multiple perspectives, in order to save time and get admission results quickly, based on AHP and Group TOPSIS technology for ranking the

alternatives. Yu et al. (2018) applied AHP process to get the optimal design of weight, power consumption and stiffness. At present, there were many methods to optimize the diamond coating parameters and some results had been achieved. However, they all needed lots of experimental data to analyze the influence of multiple parameters and took lots of time, which lacked a ranking of the importance of influencing factors. Even when little was known about the processes and the mechanisms, the Taguchi method and AHP method were used to analyze the influencing factors to obtain the optimal ranking. Finally, the experiments were carried out for targeted verification and the effect was significant.

In this paper, substrate temperature, total pressure, methane flow and carbon dioxide flow were considered to deposit diamond coatings on WC/Co (6 wt.%) substrates under $\text{CH}_4/\text{H}_2/\text{CO}_2$ atmosphere. To study the influence of parameters on the diamond coating, the Taguchi method and AHP method were used to determine the parameter plan and the sequence of the parameter plan, respectively. Finally, the best parameters were verified through experiment.

2. EXPERIMENT

2.1. Deposition and characterization

The diamond-coated substrate was cemented carbide of the WC/Co (Co 6 wt. %) which the dimensions were $12 \times 12 \times 2 \text{ mm}^3$. In order to decrease the content of surface metallic cobalt, pretreatment was required before the diamond coating deposited. (1) Alkaline etching of the Murakami's reagent ($\text{K}_3[\text{Fe}(\text{CN})_6] \cdot \text{KOH} : \text{H}_2\text{O} = 1 : 1 : 10$) removed part of the WC in the cemented carbide for 30 min, so that the cobalt was exposed and easier to be removed by acid etching; (2) Then the WC-Co substrates were immersed in the Caro's acid (10 mL $\text{HCl} : 40 \text{ mL } \text{H}_2\text{O}_2$) at 60°C for 30 s to further etch the cobalt element still existed on the surface; (3) in order to increase the

nucleation density, grind inganone with $4.5 \pm 0.45 \mu\text{m}$ diamond powder and mechanical scratch substrate for about 30 min.

During experiments, the growth of the diamond films with a 2 kW, 2.45 GHz microwave plasma chemical vapor deposition (MPCVD) was synthesized. MPCVD devices required rigorous checks before they could be used. After the blow was vacated under a basic vacuum (approximately 0.1 Pa), the microwave reaction chamber was first pumped into 200 sccm H_2 (99.999%). Further cobalt removal could be carried out by H_2 plasma etching method, and the sample scanned for 10 minutes. With the addition of CH_4 gas and CO_2 gas, the total pressure and microwave power needed to be adjusted accordingly. What's more, the gas should be fully blended that was mixture gas before input to the chamber. After the mixture gas was completely stable, deposition duration was determined at 10 hours. The infrared thermometer detected the substrate temperature through the observe window (about 1 meter in height) for coating deposition. The parameters used to prepare the diamond coating orthogonal experiment are shown in **Table 1**. The deposition experiments of four factors three levels conducted based on the Taguchi method (Salgueiredo et al. 2011). Four deposition parameters including t , p , M and C were defined as factors.

Table 1. L_9 orthogonal experiment four factors three levels.

Factors	Levels		
	1	2	3
$t/^\circ\text{C}$	650	700	750
p/kPa	6.0	7.5	9.0
$M/(\text{mL} \cdot \text{min}^{-1})$	5	6	7
$C/(\text{mL} \cdot \text{min}^{-1})$	4	6	8

As presented in **Table 2**, Taguchi array of deposition conditions and analytical results were listed. Scanning electron microscopy (SEM, S-2360N, HITACHI, Japan) was used to detect the surface morphology and crystal grain size of the diamond coating, and the magnification allows the naked eye to observe the micro-nano-level surface morphology. Raman

(LabRam HR Evolution, HORIBA, Japan), through 632 nm He-Cd laser, showed different spectral peaks on the sample surface. The adhesion between the substrate and the film could be qualitatively evaluated by the indentation morphology of Rockwell indentation tests (HR-150A).

Table 2. Experimental layout using $L(3^4)$ deposition parameters and results.

Sample No.	$t/^\circ\text{C}$	p/kPa	$M/(\text{mL} \cdot \text{min}^{-1})$	$C/(\text{mL} \cdot \text{min}^{-1})$	$v/(\mu\text{m} \cdot \text{h}^{-1})$	Q	σ/GPa
I	1	1	1	2	1.00	1.00	0.27
II	1	2	2	1	0.94	1.21	0.28
III	1	3	3	3	0.94	1.55	0.27
IV	2	1	2	3	2.04	1.07	0.27
V	2	2	3	1	0.82	1.33	0.38
VI	2	3	1	2	1.02	1.02	0.33
VII	3	1	3	2	0.94	1.10	0.29
VIII	3	2	1	3	1.08	1.05	2.10
IX	3	3	2	1	0.74	0.99	0.29

2.2. Experimental Design and Statistical Analysis

AHP calculation steps:

Step 1: Building a hierarchical model.

According to the relationship between them, the object layer, criterion layer and scheme layer of decision-making were defined into the three layers.

And a hierarchical structure diagram was drawn in [Fig. 1](#).

Fig. 1. AHP-hierarchy structure.

Step 2: Pairwise comparison matrix.

Establish the influence matrix of related factors as represented in eq. (1) and identify the importance ranking of related factors in **Wind and Saaty (1980)**.

$$A = \begin{pmatrix} x_{11} & \square & x_{1n} \\ \square & \square & \square \\ x_{n1} & \square & x_{nn} \end{pmatrix} \text{ where, } \begin{cases} x_{ij} = 1 \\ x_{ji} = \frac{1}{x_{ij}} \end{cases} \quad (1)$$

Step 3: Consistency test.

1. Calculate the normalization of each column of the judgment matrix A.

$$\begin{cases} \varpi_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \\ w_i = \sum_{j=1}^n \varpi_{ij} \\ W_i = \frac{w_i}{\sum_{i=1}^n w_i} \end{cases} \quad (2)$$

$$W = (w_1, w_2, \square, w_n)^T$$

2. Calculate the maximum feature value approximation.

$$\lambda_{\max} = \sum_{i=1}^n \frac{(AW)_i}{nW_i} \quad (3)$$

3. Consistency index.

$$\begin{cases} C.I. = \frac{\lambda_{\max} - n}{n - 1} \\ C.R. = \frac{C.I.}{R.I.} \end{cases} \quad (4)$$

Where n , $C.I.$, $R.I.$, $C.R.$, $\lambda_{\max}$ of the judgment matrix are the order, the coincidence indicator, the average random consistence indicator (**Yu et al. 2018**), the random consistence ratio and the maximum value of the matrix eigenvalue, respectively. If it is $<10\%$, $C.R.$ is acceptable (**Sherekar and Tatikonda 2016**). And if not, then the comparisons need to modify.

Step 4: Hierarchical total ranking and decision.

Determine the ranking of the relative importance and the influencing factors of each layer to the overall goal in **Table 3**.

Table 3. Hierarchical total order.

C	C_1	C_2	$\cdots$	C_m	$V_i=S \times C$
	w_1	w_2	$\cdots$	w_m	
S					
S_1	v_{11}	v_{12}	$\cdots$	v_{1m}	$V_1 = \sum_{j=1}^m w_j v_{1j}$
S_2	v_{21}	v_{22}	$\cdots$	v_{2m}	$V_2 = \sum_{j=1}^m w_j v_{2j}$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
S_n	v_{n1}	v_{n2}	$\cdots$	v_{nm}	$V_3 = \sum_{j=1}^m w_j v_{nj}$

Where the factors $C_1, C_2, \cdots, C_m$, of the criterion layer rank the total target object layer as (feature vector) is $W = (w_1, w_2, \cdots, w_m)^T$.

The n factors of the scheme layer rank the single factor C_j in the upper layer criterion layer as (feature vector) is $v_{1j}, v_{2j}, \cdots, v_{nj} (j = 1, 2, \cdots, m)$;

The total ranking of the scheme layer is that the weight of the i -th factor of the object layer to the total target is $\sum_{j=1}^m w_j v_{ij}$.

3. RESULTS AND DISCUSSION

3.1. Characterization

The pattern characterization was magnified 2000 times and the morphology of the sample could be clearly observed in **Fig. 2**. At 650 °C, in **Fig. 2a, 2b**, and **2c**, the morphology of the diamond coatings was basically clear and there were a large number of secondary nucleation, indicating that the energy of the system was low and it could not provide enough energy for the continuous growth of diamond. From **Fig. 2d, 2e**, and **2f**, at 700 °C, the grain size changed from small to large, that was, the trend of changing from fine crystal diamond, microcrystalline diamond (100) and microcrystalline diamond (111). At 750 °C, the diamond coating had a vague shape and severe etching in **Fig. 2g, 2h**, and **2i**. It showed that the system energy was large, the etching group H ions and O ions were active and the diamond

surface was seriously etched. It was still necessary to optimize the parameters in order to obtain the best diamond coating.

Fig. 2. The SEM photographs of morphologies : (a) I ; (b) II ; (c) III; (d) IV; (e) V ; (f) VI; (g) VII; (h) VIII; (i) IX.

The Rockwell indentation method was used to detect the adhesion between the film and the substrate: the top angle of the diamond indenter was $120^{\circ} \pm 15'$, the top corner radius was $0.1 \pm 0.01 \text{ mm}$ and the load was 980 N. The greater the residual stress, the greater the damage area of the film surface. However, the shedding area of the film was small and the film rupture mainly occurred around the indentation, indicating the good adhesion between the film and the substrate. As shown in **Fig. 3a-d**, the corresponding diamond coating crack diameters were 0.81, 0.63, 0.56 and 0.74 mm, respectively. **Figure 3a** showed that the diamond coating had smaller grains, contained more non-diamond components and emerged the larger cracks; **Figure 3c** showed that the diamond coating had larger grain sizes, smaller cracks and no obvious radial cracks. It showed that the appropriate deposition temperature and methane concentration were

beneficial to the deposition of high-quality diamond coatings and it was necessary to continue to optimize to obtain high-quality coatings.

Fig. 3. Indentation morphologies of diamond films: (a) I ;(b) III;(c) VI; (d) VIII.

All deposited experiments of the obtained spectra was presented in [Fig. 4](#) and [Fig. 5](#). Raman spectra of diamond films had taken at test points on (a) samples II (II , represented Raman's original curve and showed in black) and the PL background signal (Y1, reproduced with apolynomial function and shown in red);(b) has been subtracted to yield the Raman spectra which were then fitted using six Lorentzian functions. The representative spectra and corresponding peaks were all shown in [Fig. 5](#), where the obtained Raman data were the Raman spectra after the Y1 baseline subtraction; the Raman-fitting was the Raman spectra after the L fitting; AS was the fitted peak of the amorphous sp^3 phase; DIA was the diamond phase; TP was the trans-polyacetylene; G was the graphitic band; D was the disordered carbon band.

The characteristic peak was shifted from the diamond standard 1332 cm^{-1} , which was caused by the internal stress of the film. Due to the different

coefficients of thermal expansion between the base material and the diamond, residual stress accumulated, resulting in lattice distortion and shifting of the diamond peak. The characteristic peaks between 1450 cm^{-1} and 1600 cm^{-1} showed sp^2 structure of non-diamond carbon phase structure. Since the sensitivity of sp^2 structure to Raman spectrum was about 50 times higher than that of sp^3 structure, it indicated that the film was dominated by diamond. There were a large number of other characteristic peaks of non-diamond structure in the **Fig. 5**. The characteristic peaks between 1400 cm^{-1} and 1500 cm^{-1} were graphite phase (sp^2) structure, because the diamond film contained other carbon phase structures with higher composition. The D peak of the graphite structure appeared at 1480 cm^{-1} . The characteristic peaks between 1500 cm^{-1} and 1600 cm^{-1} were the graphite peak (G peak), indicated that the diamond film contained a large number of nano-sized particles. The characteristic peak between 1100 cm^{-1} and 1300 cm^{-1} was the trans-polyacetylene, and the diffusion and aggregation of H in the film was the main reasons. In **Fig. 5c-d**, the diamond peak was much sharper in all test data, which showed 1332.18 cm^{-1} and 1333.25 cm^{-1} , respectively. In **Fig. 5f**, there also had the trans-polyacetylene and graphite (sp^2) structure which are corresponding to the band at 1450.16 cm^{-1} and 1580.26 cm^{-1} (**Yang et al. 2001**). What was more, peak at $\sim 1265.93\text{ cm}^{-1}$ in **Fig. 5g** was ascribed to the amorphous sp^3 -bonded carbon and peak at $\sim 1171.05\text{ cm}^{-1}$ in **Fig. 5i** was presented the trans-polyacetylene. Based on Raman data, two indicators of coating quality and residual stress were obtained, which provided a prerequisite for better analysis of coatings.

Fig. 4. Raman spectra of diamond films taken at test points on: (a) samples II (Raman's original curve and showed in black) and the PL background signal (Y1, reproduced with apolynomial function and shown in red);(b)has been subtracted to yield the Raman spectra which are then fitted using six Lorentzian functions.

Fig. 5. Raman spectra of as-deposited diamond films with same thickness (~20 μm): (a) I ; (b) II ; (c) III; (d) IV; (e) V ; (f)VI; (g) VII; (h) VIII; (i) IX.

3.2. Optimisation of the diamond films

According to SEM and Raman spectroscopy analysis, the analysis results of growth rate, coating quality and residual stress were shown in [Table 2](#).

The thickness of the coating was measured by an average of five points with the spiral micrometer (1 μm). The coating growth rate was approximately equal to the coating thickness divided by the deposition time. The quality of the diamond coating through Raman spectrum was shown by Eq. 5, where I_D was the diamond peak and I_G was the graphite peak (Sails et al. 1996).

$$Q = \frac{I_D}{I_G} \quad (5)$$

The residual stress in diamond coating could pass through the position of diamond peaks in Raman spectroscopy and the natural non-residual diamond peak position of internal stress pure diamond (1332.2 cm^{-1}) to calculate the gap between the Raman frequency shift (Ferreira et al. 2002). Raman frequency shift to a smaller numerical direction offset, there was residual tensile stress in the surface diamond coating. The residual stress values could be calculated by Eq. (6):

$$\sigma = -0.567\Delta\nu(\text{cm}^{-1}) \quad (6)$$

Where: σ is the fracture strength determined the residual stress; $\Delta\nu$ is the offset of Raman displacement.

The growth rate was correspondent to the three deposition temperature which was calculated as follows:

Level 1: 650 $^{\circ}\text{C}$	$(0.94+1.08+0.74)/3=0.92$
Level 2: 700 $^{\circ}\text{C}$	$(2.04+0.82+1.02)/3=1.30$
Level 3: 750 $^{\circ}\text{C}$	$(1.00+0.94+0.94)/3=0.96$

In order to obtain high growth rate, good coating quality and small residual stress, used Taguchi method to process the data in Table 4 and the data change trend in Figure 5.

Table 4. L9(3⁴) Taguchi array of analysis results.

Level	$t/^{\circ}\text{C}$	p/kPa	$M/(\text{mL} \cdot \text{min}^{-1})$	$C/(\text{mL} \cdot \text{min}^{-1})$
1	0.96	1.33	0.85	1.24

ν	2	1.29	0.95	0.97	0.83
	3	0.92	0.90	1.35	1.03
	K	0.38	0.43	0.50	0.34
Q	1	1.05	1.06	1.33	1.22
	2	1.14	1.20	1.02	1.11
	3	1.25	1.19	1.09	1.11
σ	K	0.20	0.14	0.31	0.11
	1	0.89	0.28	0.48	0.88
	2	0.49	1.08	0.90	0.48
	3	0.27	0.30	0.28	0.30
	K	0.62	0.80	0.61	0.58

Based on these assumptions in Table 4 and Figure 5, the primary and secondary order of factors under each index for ν was $M > p > t > C$ through range chart analysis. According to the average of different levels of each index, determining the optimal level combination of each factor was $t_2p_1M_3C_1$. The influence trend and primary and secondary order of Q and σ were showed as $M > t > p > C$ and $p > t > M > C$, respectively. Optimization plan of Q and σ was $t_3p_2M_1C_1$ and $t_3p_1M_3C_3$, respectively.

Fig. 6. Variance trend on the growth rate (ν), diamond quality factor (Q) and total residual stress (σ).

3.3. AHP method

Step 1: Building a hierarchical model.

The object layer to make sure the goal was the optimal deposition parameters. The criterion layer was affected by four factors to achieve this goal, including temperature pressure, methane content and carbon dioxide content. The scheme layer included three plans, which were scheme 1 ($t_2p_1M_3C_1$), scheme 2 ($t_3p_2M_1C_1$), scheme 3 ($t_3p_1M_3C_3$) in order. Development of hierarchy structure was shown in Fig. 5.

Fig.7. Hierarchical design based AHP.

Step 2: Pairwise comparison matrix.

Calculated the normalization of each column of the judgment matrix.

Construct the judgment matrix by eq. (1).

$$A = \begin{bmatrix} 1 & 5 & 7 & 3 \\ 1/5 & 1 & 3 & 1/3 \\ 1/7 & 1/3 & 1 & 1/5 \\ 1/3 & 3 & 5 & 1 \end{bmatrix}$$

$$C_1 = \begin{bmatrix} 1 & 1/3 & 1/8 \\ 3 & 1 & 1/3 \\ 8 & 3 & 1 \end{bmatrix} \quad C_2 = \begin{bmatrix} 1 & 2 & 5 \\ 1/2 & 1 & 2 \\ 1/5 & 1/2 & 1 \end{bmatrix}$$

$$C_3 = \begin{bmatrix} 1 & 1 & 3 \\ 1 & 1 & 3 \\ 1/3 & 1/3 & 1 \end{bmatrix} \quad C_4 = \begin{bmatrix} 1 & 3 & 4 \\ 1/3 & 1 & 1 \\ 1/4 & 1 & 1 \end{bmatrix}$$

Step 3: Consistency test.

1. According to eq. (2), the calculation was $w_A = (0.558, 0.122, 0.057, 0.263)^T$.

2. Calculated the maximum feature value approximation by eq. (3).

$$\lambda_{\max} = \frac{2.356}{4 \times 0.558} + \frac{0.492}{4 \times 0.122} + \frac{0.230}{4 \times 0.057} + \frac{1.100}{4 \times 0.263} = 4.11815$$

3. Consistency index by eq. (4).

$$\begin{cases} C.I. = \frac{4.11815 - 4}{4 - 1} = 0.0393833 \\ C.R. = \frac{0.0393833}{0.89} = 0.0442509 \end{cases}$$

If $C.R. < 0.1$, within the allowable range, meet the requirements. By analogy calculation, the weight vectors of other matrices could be obtained. The weights were as follows:

$$w_A = (0.558, 0.122, 0.057, 0.263)^T$$

$$w_{C_1} = (0.082, 0.244, 0.674)^T$$

$$w_{C_2} = (0.606, 0.265, 0.129)^T$$

$$w_{C_3} = (0.429, 0.429, 0.143)^T$$

$$w_{C_4} = (0.636, 0.185, 0.179)^T$$

Step 4: Hierarchical total ranking and decision.

The total order of the three levels of scheme 3 was 1 in Table 5 and scheme 3 was the best optimization scheme.

Table 5. Hierarchical total order.

C	C ₁	C ₂	C ₃	C ₄	V _i	Rank
S	0.558	0.122	0.057	0.263		
S ₁	0.082	0.606	0.429	0.636	0.311	2
S ₂	0.244	0.265	0.429	0.185	0.242	3
S ₃	0.674	0.129	0.143	0.179	0.447	1

3.4. Confirmation test

Analyzed the three schemes by AHP and got scheme 3 as the best plan. The best process parameter was $t_3p_1M_3C_3$, which was 750 °C, 6 kPa, 7 mL/min, 8 mL/min. In order to prove the optimized parameters, necessary experimental verification was necessary. Figure 8a showed the typical

SEM image of diamond film, preferential [100] and [110] orientation, better polycrystalline structure. By estimating the thickness, growth rate of the diamond coating could reach $1.3 \mu\text{m/h}$. The indentation morphology presented in **Figure 8b** that the crack was small and the maximum crack diameter was 0.45 mm because of the better deposition quality. **Figure 8c** showed the Raman property of diamond coating, where quality of diamond film was significantly improved, 1331.17 cm^{-1} was the sharpest peak, together with some other peaks, such as at 1429.15 cm^{-1} , 1490.12 cm^{-1} and 1564.31 cm^{-1} . The peak at $\sim 1429.15 \text{ cm}^{-1}$ and $\sim 1490.12 \text{ cm}^{-1}$ features to the trans-polyacetylene segments were likely to be concentrated at grain boundaries. And a band centered at approximately 1564.31 cm^{-1} (G band) was resultant of the graphite deposited during the coating process, indicated that the diamond film contained a large number of nano-sized particles. Compared with the diamond peak ($\sim 1332 \text{ cm}^{-1}$), the impurity peak appeared weaker, indicating that the quality of the diamond coating was relatively good. Through experimental verification, we could obtain diamond film with better deposition quality.

Fig. 8. Confirmation test:(a) SEM image; (b) Indentation morphology; (c) Raman spectra.

4. CONCLUSION

In the current work, parameter optimizations were demonstrated with CH₄/H₂/CO₂ atmosphere. To analyze multiple influencing parameters by the Taguchi and AHP method, three conclusions were as follows. Based on the maximum growth rate, the best coating quality and minimum residual stress, obtained three better deposition process parameters: $t_2p_1M_3C_1$, $t_3p_2M_1C_1$, $t_3p_1M_3C_3$ through analyzed the range of each influencing factor of Taguchi method. Analyzed the ranking weights of the three schemes for optimization importance, determined the ranking of the schemes and found that $t_3p_1M_3C_3$ was the first scheme based on AHP method. What was more, through experimental verification, the experimental and mathematical models had the good consistency. Future studying parameters including anti-erosion properties and wear characteristics must be considered to evaluate the influence of high-quality diamond coating.

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