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# STUDY ON THE ELECTRO-SPARK DEPOSITION PROPERTIES OF SKH51 TRANSITION COATING IN COMPOSITE GRADIENT COATING

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*Because of the limitation of deposition thickness in electro-spark deposition (ESD) technology, composite coatings are increasingly used in electro-spark deposition. The deposition quality of transition coating is the key to improve composite coating. The deposition quality of transition coating is the key to improve composite coating. SKH51 material belongs to tungsten and molybdenum based materials and a high-speed tool steel with small and homogenous carbide particles. It has high hardness and excellent thermal hardness. It has good impact toughness and wear resistance, and can be used as the intermediate layer of carbon steel material and super-hard cermet coating. Consequently, a gradient structure is established. In this article, SKH51 material was deposited on the surface of 45 steel by the electro-spark deposition. With orthogonal experimental design, 16 sets of deposition experiments were conducted by selecting 4 factors and 4 levels. The coating thickness, coating surface roughness and maximum wear width of 16 samples were measured and counted. SKH51 coating wear surface is mainly abrasive wear and oxidation corrosion which is due to dry friction resulting in high temperatures on the surface. Because the surface of SKH51 coating was rough, the wear mass was used, the error will be larger. So the wear mark width is used to compare the wear resistance of the samples. The normalization method was used to unify the different unit coating evaluation objectives into a single metric. Three groups of weighting factors were determined using the requirements of transition coatings for coating performance indicators. Then, it was substituted into the objective function, and each experimental group normalizes the parameters for calculation. As a result, three distinct sets of maximal goal functions were obtained. The optimal value of the objective function corresponded to the 12th sample group. Finally, the deposition process parameters of the 12th sample were regarded as the optimal process for the SKH51 transition coating.*

***Key words:*** *electro-spark deposition, composite gradient coating, steel, hardness, microhardness, surface layer, structure, coating, alloy, roughness, transition coating, normalization method, weighting factor method.*

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## Introduction

Mechanical parts are subjected to impact loads during their service life. It has a certain velocity of impact in a very short period of time. In this case, the ability of the material to resist the impact load is called the toughness of the material. The coating material utilized in the ESD)process exhibits brittleness and is susceptible to dislodgement upon impact. During the electro-spark deposition process, if the coating material is relatively brittle, the toughness of the coating needs to be enhanced. The usual solutions include grain refinement, composite strengthening and toughening, and alloying. By adopting the alloying method, SKH51 was selected as the electrode material. SKH51 is a tungsten-molybdenum series high-carbon high-speed tool steel (Thammachot et al., 2023) with high hardness (61-64HRC) and high high-temperature hardness (Chuang et al., 2011). SKH51 has good toughness (Khadem et al., 2021) and wear resistance, it is mostly used in the mold industry and in the cutting tool industry (Lawanwong et al., 2011). The steel has fine and uniform carbide particles (Shiozawa et al., 2006). The presence of molybdenum can reduce carbide segregation, and vanadium can make the steel more stable when heated. Its wear resistance is 2 times higher than high chromium high carbon steel and toughness is 1.5 times stronger. As an intermediate layer, SKH51 coating can have good compatibility (Aghajani et al., 2020) with cobalt alloys in WC-8Co, WC-10Co and WC-12Co coatings. Because ESD process is limited by the thickness and functionality of a single coating (Shafyei et al., 2020), composite coating structures are often used to make up for the shortcomings of the process (Aghajani et al., 2020). The surface properties of the intermediate coating are directly related to the coating deposition quality of the outer layer. Therefore, the improvement of the surface properties of the intermediate coating has a positive significance on the deposition quality of SKH51+WC composite gradient coatings.

Bai (Bai et al., 2021) proposed to obtain high-hardness, high-toughness wear-resistant coatings using gradient coatings by using gradient coatings, layered structural coatings, and multiple-scale structural coatings. G. Rolland (Rolland et al., 2019) used Stellite 6 electrodes of cobalt-based alloy to improve the toughness and hardness of ESD coatings. Liu (Liu et al., 2019) modified the toughness of AlCrSiN coatings with the addition of nickel material. The SKH51 material utilizes the ferrous matrix to ensure adequate toughness, and its hardened composition gives it a certain degree of wear resistance.

The fine tungsten carbide particles formed internally, which makes the SKH51 material have a certain degree of wear resistance. Metal hard compounds have high hardness and good wear resistance. Carbides and nitrides of metal elements are usually used to strengthen the surface hardness of the coating. Hossein (Aghajani et al., 2020) deposited WC/TiC/Co/Ni composite coatings on the surface of St52 steel, which increased the surface micro-hardness by 710HV. Yusuf Kayali (Kayali et al., 2021) deposited WC coatings on AISI 5140 to generate a hardness gradient structure for better wear resistance. Wang (WANG et al., 2021) used Ni and Mo as transition layers and formed a WC-Ni composite coating when the deposited coatings was made on the surface of H13 steel by ESD. Zhao Wang (Zhao et al., 2023) used the WC-10%Co coating deposition experiment on the tc11 surface and comprehensively evaluate the coating quality, and the ESD process parameters for the repair of the coating defects were determined. Mert Onan (Onan et al., 2021)uses electro-spark deposition technology to deposit double layers of WC and WC + SS (tungsten carbide and stainless steel) coatings on the surface of 45 mold steel to improve the toughness and wear resistance of the mold surface.

## Materials and Methods

### Material Analysis and Deposition Parameters

The ESD electrode used a rod with a diameter of 3mm (Jinxin Co., Ltd. China). The material utilized for its construction was SKH51, which originated from Japan, as shown in Table 1.

Table 1

**Elemental content of SKH51 alloy steel**

| Element | C | W | Si | Cr | Mo | V | Fe |
|---|---|---|---|---|---|---|---|
| Content (%) | 0.85 | 5.8 | 0.45 | 4 | 4.8 | 1.8 | other |

Firstly, 2mm thickness of 45 steel plate was cut into 25*30 mm size. Then, 240-400-800-1200 grit sandpaper was selected to grind the surface successively in order to remove the oxide layer and impurities. The samples were placed in a beaker soaked in 99 per cent anhydrous ethanol and cleaned with an ultrasonic cleaner. Then, a hair dryer was used to dry the surface of the samples. The ESD deposition equipment was selected as HMT9500 from Shanghai Shengzao Company, as shown in Fig. 1. SKH51 rod with a diameter of 3mm was selected as the electrode, and argon gas was used as the protective gas. The experiments were carried out by Taguchi OA Design of Factorial Design (Weiwei et al., 2007) for ESD deposition experiments on 45 steel surfaces, the process parameters are shown in Table 2. Based on the pre-experimental results, the parameters related to the 4-factor, 4-level test were determined, as shown in Table 3. The deposition time was 5 min each time.

**Fig. 1. The electro-spark deposition equipment (HMT9500)**

Table 2

**The ESD process parameters**

| № | Efficiency | Voltage | Current frequency | Rotate Speed |
|---|---|---|---|---|
| Unit | % | V | Hz | r/min |
| 1 | 20 (1) | 25 (1) | 100 (1) | 150 (1) |
| 2 | 30 (2) | 35 (2) | 200 (2) | 225 (1) |
| 3 | 40 (3) | 45 (3) | 300 (3) | 300 (1) |
| 4 | 50 (4) | 55 (4) | 340 (4) | 375 (1) |

() – Level values in brackets

### Materials Testing methods

After deposition of the samples, the graphite powder was wiped from the processed surfaces with a brush. The surface was then measured for roughness experiments by a roughness tester (Mitutoyo Co., Ltd., SJ-210). The ball-disc friction and wear tester MS-T300 was used for the abrasion resistance test (Huahui Instrument Co., Ltd., MS-T300), in which the test parameters were set as follows: load 5N, test time 10 min, spindle speed 600 r/min, and test radius 3.5 mm. 5mm friction balls ($ZrO_2$, G10 precision) were used for the surface abrasion test. After the test, the powder on

Table 3

**Taguchi OA experimental scheme for SKH51 deposition experiments**

| № | Efficiency | Voltage | Current Frequency | Rotate Speed |
|---|---|---|---|---|
| Unit | % | V | Hz | r/min |
| 1 | 25 | 20 | 100 | 150 |
| 2 | 30 | 28 | 100 | 225 |
| 3 | 35 | 36 | 100 | 300 |
| 4 | 40 | 44 | 100 | 375 |
| 5 | 30 | 20 | 200 | 300 |
| 6 | 25 | 28 | 200 | 375 |
| 7 | 40 | 36 | 200 | 150 |
| 8 | 35 | 44 | 200 | 225 |
| 9 | 35 | 20 | 300 | 375 |
| 10 | 40 | 28 | 300 | 300 |
| 11 | 25 | 36 | 300 | 225 |
| 12 | 30 | 44 | 300 | 150 |
| 13 | 40 | 20 | 400 | 225 |
| 14 | 35 | 28 | 400 | 150 |
| 15 | 30 | 36 | 400 | 375 |
| 16 | 25 | 44 | 400 | 300 |

the surface of the parts was removed by brushing, and the scratches were wiped with anhydrous alcohol and dried naturally. The abrasion marks were measured by a microscope (Leica Co., Ltd., DM6).

**Results and Discussion**

**1. Coating Thickness**

The experiments were carried out to measure the thickness of the deposited surface according to the orthogonal experimental scheme in Table 3. Measurements were carried out on the surface at five specific places, and which of values were averaged in order to eliminate the measurement error. According to the orthogonal experiment Table 4 (Hazra et al., 2022), the coating thickness is able to reflect the deposition quality of the coating. The extreme value R of the orthogonal table is found to be in the measurement range of these experiments. The larger the value of the extreme value R reflects the large influence of this factor on the coating thickness. The order of factors affecting the thickness of deposition: Rotate Speed > Current Frequency > Voltage > Efficiency. The rotate speed of ESD deposition process parameter has the greatest effect on the thickness of the deposited layer; Efficiency has a lesser effect on the deposited thickness. The larger the electrode rotate speed, the larger the thickness of the deposited coating. However, due to the high speed of the electrode, the uniformity of the deposition process on the surface will become worse, and the friction of the electrode movement will increase during the experiment. In Fig. 2, sample 15 has the largest coating thickness with a value of 45.9 μm; Samples 10, 12, 14, 15 and 16 were the alternative feasible solutions.

**2. Coating roughness**

The deposited surface was measured by Mitutoyo SJ-210 roughness meter. The roughness meter was selected from the ISO 1997 standard and the surface was measured over a length of 3mm. The objective of this study is to perform roughness measurement on the surface of SKH51 coating. Three measurements will be conducted on each sample surface, and the average value of Ra for the sample will be calculated. The results were analysed on the basis of

Table 4

**Taguchi OA Experiments on Coating Thickness**

| № | Efficiency | Voltage | Current Frequency | Rotate Speed | Coating Thickness (μm) |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 11.1 |
| 2 | 2 | 2 | 1 | 2 | 12.4 |
| 3 | 3 | 3 | 1 | 3 | 16.6 |
| 4 | 4 | 4 | 1 | 4 | 24.1 |
| 5 | 2 | 1 | 2 | 3 | 10 |
| 6 | 1 | 2 | 2 | 4 | 15.6 |
| 7 | 4 | 3 | 2 | 1 | 20.9 |
| 8 | 3 | 4 | 2 | 2 | 20.2 |
| 9 | 3 | 1 | 3 | 4 | 18.7 |
| 10 | 4 | 2 | 3 | 3 | 36.9 |
| 11 | 1 | 3 | 3 | 2 | 17.2 |
| 12 | 2 | 4 | 3 | 1 | 34.1 |
| 13 | 4 | 1 | 4 | 2 | 26.7 |
| 14 | 3 | 2 | 4 | 1 | 40.6 |
| 15 | 2 | 3 | 4 | 4 | 45.9 |
| 16 | 1 | 4 | 4 | 3 | 40.3 |
| **K1j** | 26.725 | 16.675 | 16.05 | 38.375 | |
| **K2j** | 25.15 | 26.375 | 16.625 | 29.675 | |
| **K3j** | 24.025 | 25.6 | 21.05 | 27.15 | |
| **K4j** | 25.95 | 19.125 | 26.675 | 26.075 | |
| **R** | 2.7 | 9.7 | 10.625 | 12.3 | |

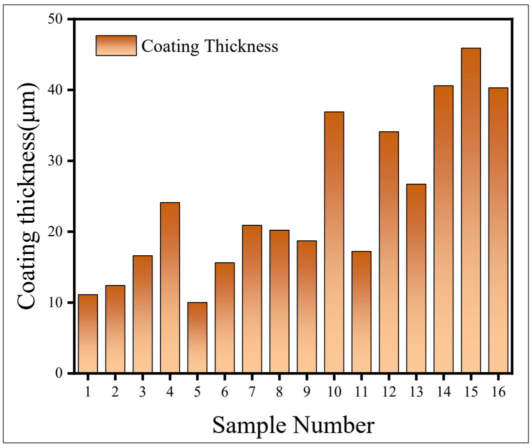



**Fig. 2. Deposition quality and coating thickness of SKH51 coating**

the orthogonal experimental scheme. The influence of ESD deposition parameters is reflected based on the extreme values of R in the orthogonal table. As shown in Table 5, the order of effect of deposition factors: Rotate Speed > Voltage > Current Frequency > Efficiency. By average roughness values, it is found that rotate speed has a significant effect on surface roughness than other process parameters. At a certain energy, too much and too little rotate speed causes an increase in surface roughness. Thus, when the three process parameters of Current Frequency, Voltage and Efficiency increase, the energy is greater ; when the energy increases, the coating thickness increase, but the surface roughness value will increase. As shown in Fig.3, sample 14, 15, and 16 appeared larger roughness. There was a tendency for surface roughness to decrease with smaller deposition thickness. However, too small a thickness was not conducive to the formation of a transition layer, even if there was a good roughness. Samples 4, 12 and 10 were feasible options.

Table 5

**Taguchi OA Experiments results for mean values of coating roughness**

| Extreme | Efficiency | Voltage | Current Frequency | Rotate Speed |
|---|---|---|---|---|
| R | 0.0805 | 0.2225 | 0.10375 | 0.319 |

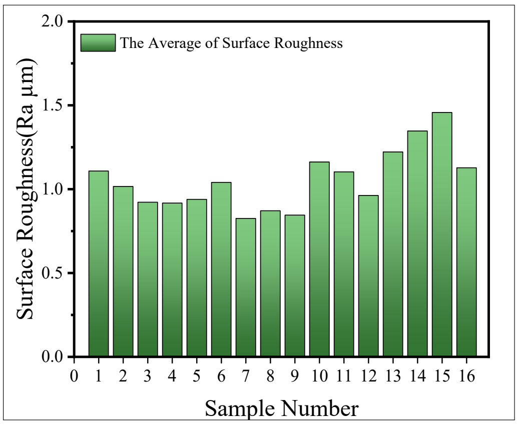
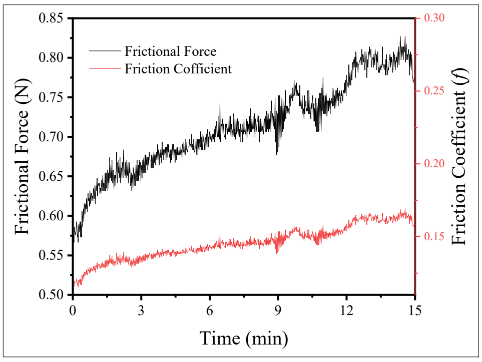



**Fig. 3. Average of Surface Roughness**

### 3. Abrasion resistance tests of SKH51 coating

The wear resistance of SKH51 coatings were analyzed with a rotary friction and wear machine MS-T300 (Huahui Co., Ltd. China). A load of 5N was selected to carry out the wear resistance experiment on the metal surface, as shown in Fig.4a. In Fig.4b, SKH51 coating wear surface was mainly abrasive wear and oxidation corrosion which was due to dry friction resulting in high temperatures on the surface. Because the surface of SKH51 coating was rough, the wear mass was used, the error will be larger. So the wear mark width is used to compare the wear resistance of the samples. The maximum width of the wear marks was measured by super depth-of-field microscope, as shown in Fig. 4c. Owing to the influence of coating surface roughness, it makes the wear marks uneven, and its friction force and friction coefficient cannot truly reflect the degree of wear resistance. The maximum width of the abrasion marks was utilized to eliminate the effect of surface roughness and coating topography. Under 25 °C experimental environment three experiments were carried out for every specimen . The data were measured separately and subsequently averaged for analysis, as shown in Fig. 5. In Table 6, according to the orthogonal experiment of extreme value R, the order of effect of deposition factors: Current Frequency > Efficiency > Rotate Speed > Voltage. Current Frequency and Efficiency have a greater influence relative to the other parameters, which make the abrasion resistance of the coating worse. As shown in Fig. 5, sample 15 has the largest wear width and the worst abrasion resistance. Sample 15, 8, 4, 3, 7 and 10 have larger widths of abrasion marks and poorer abrasion resistance.

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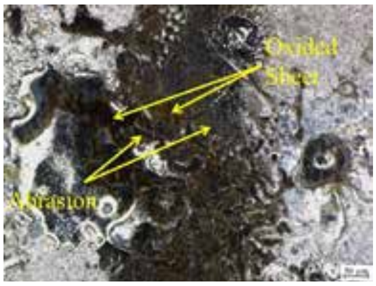


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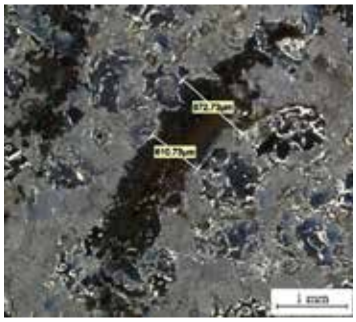


**c)**

**Fig. 4. SKH51 coating friction and wear experimental results:**
a) Friction coefficient and friction; b) Friction and wear morphology; c) Abrasion measurement

Table 6

**Taguchi OA Experiments Extreme for the average of the maximum wear width of SKH51 coating**

| Extreme | Efficiency | Voltage | Current Frequency | Rotate Speed |
|---|---|---|---|---|
| R | 90.4125 | 65.7925 | 111.18 | 76.1025 |

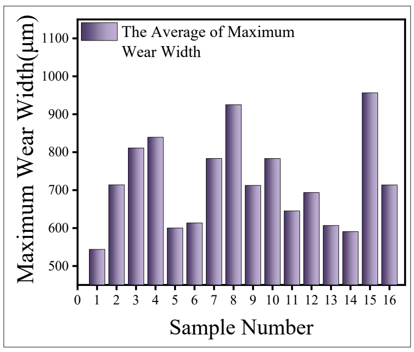



**Fig. 5. Average of Maximum Wear Width of SKH51 Coatings**

**Model evaluation**

SKH51 transition coatings can be comprehensively evaluated based on coating thickness, coating roughness and wear width. As transition coatings need serve the deposition of external coatings, they should give priority to the coating thickness and the coating roughness. A multi-objective optimal design problem (Sharafi et al., 2014) is a problem in which two or several design objectives are required to be optimal at the same time in an optimal design. If there is no unified metric for each sub-objective in objectives, it will be difficult to compare. In 1772 Franklin proposed the multi-objective problem, by now the multi-objective optimization problem has a variety of mature optimization theories and has been applied in engineering optimal design. This model uses the normalization method and the weighted factor method to transform multiple evaluation factors into a single-objective method, as shown in Formula 1.

**Normalization method**

Normalization method is to eliminate the effect of different units of each factor. According to the physical significance of the numerical magnitude of the factors, different functions of efficacy coefficients are selected for normalization (Landes et al., 1991; Yang et al., 2021). Coating thickness, roughness and wear width have different units, which are processed using a normalization method (Zhang et al., 2023). Higher values of average coating thickness mean better performance. It is processed according to the increasing function of the efficiency coefficient. The data were substituted into Equation 3. The smaller values of average wear width marks and average roughness mean the better performance. It is processed according to the decreasing function of the efficiency coefficient. The corresponding data were substituted into Equation 4. Eventually, the normalized data for the coating parameters were obtained as shown in Table 8.

$$f(X)=\sum_{j=1}^{n} a_j f_j(X) \tag{1}$$

$$\sum_{j=1}^{n} a_j = 1 \quad a_i \geq 0 \tag{2}$$

The evaluation factors were normalised due to the different units of the factors:

1) To denote the monotonically increasing efficacy coefficient function:

$$d_j=\begin{cases} 0 & f_j(\boldsymbol{x}) \leqslant \alpha_j \\ (f_j(\boldsymbol{x})-\alpha_j)/(\beta_j-\alpha_j) & \alpha_j < f_j(\boldsymbol{x}) < \beta_j \\ 1 & f_j(\boldsymbol{x}) \geq \beta_j \end{cases} \tag{3}$$

2) To denote the monotonically decreasing efficacy coefficient function:

$$d_j=\begin{cases} 1 & f_j(\mathbf{x}) \leq \alpha_j \\ 1-(f_j(\mathbf{x})-\alpha_j)/(\beta_j-\alpha_j) & \alpha_j < f_j(\mathbf{x}) < \beta_j \\ 0 & f_j(\mathbf{x}) \geq \beta_j \end{cases} \tag{4}$$

Table 7

**SKH51 coating performance parameters**

| № | Average coating thickness (μm) | Average of Surface Roughness (μm) | Average of Maximum Wear Width (μm) |
|---|---|---|---|
| 1 | 11.1 | 1.108 | 543.67 |
| 2 | 12.4 | 1.016 | 713.91 |
| 3 | 16.6 | 0.922 | 810.84 |
| 4 | 24.1 | 0.917 | 839.41 |
| 5 | 10.0 | 1.533 | 600.24 |
| 6 | 15.6 | 1.040 | 613.44 |
| 7 | 20.9 | 0.825 | 783.42 |
| 8 | 20.2 | 0.871 | 925.23 |
| 9 | 18.7 | 0.845 | 712.45 |
| 10 | 36.9 | 1.162 | 783.23 |
| 11 | 17.2 | 1.103 | 645.15 |
| 12 | 34.1 | 0.962 | 693.47 |
| 13 | 26.7 | 1.222 | 606.75 |
| 14 | 40.6 | 1.347 | 590.41 |
| 15 | 45.9 | 1.457 | 956.54 |
| 16 | 40.3 | 1.127 | 713.58 |

Table 8

**Normalized data table for coating parameters**

| № | Average coating thickness | Average of Surface Roughness | Average of Maximum Wear Width |
|---|---|---|---|
| 1 | 0.03064 | 0.60028 | 1.00000 |
| 2 | 0.06685 | 0.73023 | 0.58767 |
| 3 | 0.18384 | 0.86299 | 0.35290 |
| 4 | 0.39276 | 0.87006 | 0.28370 |
| 5 | 0.00000 | 0.00000 | 0.86298 |
| 6 | 0.15599 | 0.69633 | 0.83101 |
| 7 | 0.30362 | 1.00000 | 0.41931 |
| 8 | 0.28412 | 0.93503 | 0.07584 |
| 9 | 0.24234 | 0.97175 | 0.59120 |
| 10 | 0.74930 | 0.52401 | 0.41977 |
| 11 | 0.20056 | 0.60734 | 0.75421 |
| 12 | 0.67131 | 0.80650 | 0.63717 |
| 13 | 0.46518 | 0.43927 | 0.84722 |
| 14 | 0.85237 | 0.26271 | 0.88679 |
| 15 | 1.00000 | 0.10734 | 0.00000 |
| 16 | 0.84401 | 0.57345 | 0.58847 |

**Weighted factor method**

A weighting factor refers to the coefficient of relative influence or weight assigned to an individual sub-objective (Kilic et al., 2006). The weighting factor method (Dragičević et al., 2018)is based on the importance and specific attributes of each variable or sub-objective. To ensure the unity of evaluation, the weighting factor method requires that the sum of the weighting factors of each factor must be 1. Transitional coatings are firstly considered to have a better surface quality of the coating to facilitate the deposition of subsequent coatings. Transitional coatings are firstly considered to have a better surface quality of the coating to facilitate the deposition of subsequent coatings. Secondly, it is considered to have a certain coating thickness. finally, it is considered that the transitional coating has a certain degree of wear resistance than the substrate. Therefore, the weighting factors are selected taking into account the characteristics of the transition coating. The order of the selected factors is: coating roughness > coating thickness > maximum abrasion mark width. Three weighting factors were taken respectively. Therefore, according to the above factors, the weighting factors are selected from the table 9.

Table 9

**Weighting factors for coating performance parameters**

| № | Average coating thickness | Average of Surface Roughness | Average of Maximum Wear Width |
|---|---|---|---|
| Scheme 1 | 0.4 | 0.35 | 0.25 |
| Scheme 2 | 0.5 | 0.3 | 0.2 |
| Scheme 3 | 0.6 | 0.25 | 0.15 |

The normalized values of the schemes in each factor were multiplied by the corresponding weighting factors, and then summed to obtain the target values for each alternative solution (Acar et al., 2009). The experimental solutions were evaluated to arrive at the optimal solution. The maximum value of the objective function was calculated by substituting the normalized data in Table 8 and the weighting factors in Table 9 into Equation 1. The results of the objective function are shown in Fig. 6.

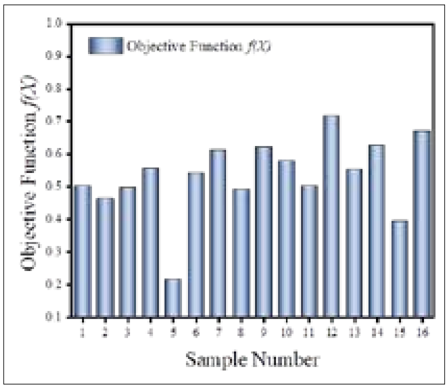
$$\mathrm{MAX} \quad f(X) = \sum_{j=1}^{n} a_j d_j \qquad \left( \sum_{i=1}^{n} a_i = 1 \quad a_i \geq 0 \right)$$

By comparing the values of the objective functions, the three objective functions of sample 12 are all the maximum value, and the comprehensive evaluations of the transition coating are optimal in Table 9. The deposition process parameters are Current Frequency at 300 Hz; Voltage at 44 V; Efficiency at 30 %; and Rotate Speed at 150 r/min. In addition, it was suggested that sample 7 and sample 9 could be used as an alternative for the deposition of the transition layer.

**Conclusions**

In SKH51+WC composite coating, the SKH51 coating that functions as an intermediate layer has a significant impact on the deposition quality of the composite coating. SKH51 coating was deposited on No. 45 steel in the experiment. With the orthogonal experimental design method, the effects of electro-spark deposition parameters on the average thickness of the coating, the average width of the maximum wear mark, and the average roughness were discussed. It was discussed respectively the effect of electro-spark deposition parameters on the average of the coating thickness, the average width of the maximum wear width, and the average roughness. It was found that each parameter had different effects on the properties of SKH51 coating. According to the normalization method and weighted factor method, the optimum deposition process of the coating was obtained from the performance requirements of the transition layer.

1) The influence of ESD process parameters, which were rotate speed, current frequency, voltage and efficiency was considered on the performance parameters of SKH51 coating respectively by the orthogonal experimental method. Rotate speed has a greater influence on the deposition thickness and coating roughness. Voltage has a greater influence on the reduction of abrasion width and the enhancement of abrasion resistance.

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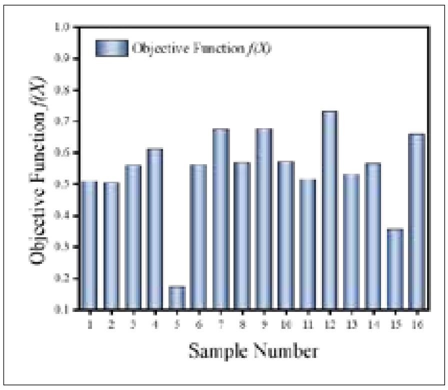


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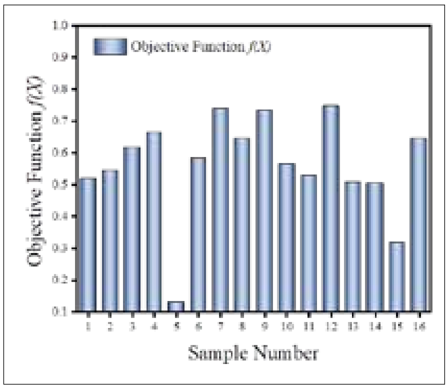


c)

**Fig. 6. Objective function diagram:**

a) Weighting factor scheme 1; b) Weighting factor scheme 2; c) Weighting factor scheme 3

2) The average coating thickness, average maximum wear width, and average roughness of the SKH51 coating were analyzed from the perspective of transition coating. The normalization method and weighting factor method were used to conduct target evaluation of coating performance parameters. Three different weighting factors were selected to evaluate the SKH51 coating and draw consistent conclusions.

3) The optimal deposition process is obtained with the use of a comprehensive evaluation. The optimal deposition process parameters are Current Frequency 300Hz; Voltage 44 V; Efficiency 30 %; Rotate Speed 150 r/min.

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***Дослідження властивостей перехідного шару зі сталі SKH51, сформованому електроіскровим легуванням в композитному градієнтному покритті***

*В зв'язку з технологічними обмеженнями максимальної товщини наплавленого методом електроіскрового легування шару все частіше застосовуються багатошарові композитні покриття. Важливу роль в забезпечені експлуатаційних параметрів композитного покриття відіграє якість перехідного шару. В статті досліджуються властивості перехідного шару зі сталі SKH51, яка є швидкоріжучою інструментальною сталлю, легованою вольфрамом і молібденом та містить в своїй структурі до матеріалів на основі вольфраму та молібдену і є високошвидкісною інструментальною сталлю з дрібними та однорідними частинками карбіду. Перевагами цієї сталі є: висока твердість, хороша ударна в'язкість і зносостійкість, може використовуватися як проміжний шар між вуглецевою сталлю та надтвердим металокерамічним покриттям. При цьому, в композитному покритті формується градієнтна структура. У даній статті дослідження особливостей формування проміжного шару з сталі SKH51, що нанесений на поверхню сталі 45 методом електроіскрового легування. Було проведено серію з 16 експериментів, в яких було встановлено 4 рівні значень для чотирьох параметрів процесу електроіскрового легування. Контролювалися наступні параметри: товщина покриття, шорсткість поверхні та максимальна ширина зносу 16 зразків. Встановлено, що при зношуванні поверхні покриття SKH51 відбувається переважно абразивне зношування та окислювальна корозія, які виникають в умовах внаслідок сухого тертя призводить до високих температур на поверхні. Для порівняння зносостійкості зразків використовується ширина сліду зносу, що дозволило зменшити похибку вимірювання в порівнянні з ваговим зносом в наслідок пористості отриманого покриття. Метод нормалізації було використано для об'єднання різних цілей оцінки одиничних покриттів в єдину метрику. Було визначено три групи вагових коефіцієнтів з використанням вимог перехідних покриттів до показників ефективності покриття. Отримані значення було підставлено в цільову функцію, і для кожної експериментальної групи визначено нормалізовані розрахункові параметри. В результаті було отримано три різні набори максимальних значень цільових функцій. Оптимальне значення цільової функції відповідало 12-й групі зразків. Таким чином, параметри процесу електроіскрового легування 12-го зразка приймаємо як оптимальні для процесу формування перехідного покриття зі сталі SKH51.*

***Ключові слова:*** *електроіскрове легування, сталь, композитне градієнтне покриття, твердість, мікротвердість, поверхневий шар, структура, покриття, сплав, перехідний шар, шорсткість, метод нормалізації, метод вагових коефіцієнтів.*