APPLICATION OF WC-Ni PLASMA SPRAY COATING TECHNOLOGY TO RESTORE AND ENHANCE WEAR RESISTANCE FOR LATHE SLIDEWAYS

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ABSTRACT

Wear is one of the main causes of damage and reduced performance of machine parts operating under harsh conditions. In practice, various types of wear exist, making wear control and durability enhancement crucial concerns for manufacturing industries. This paper explores the application of plasma spray coating technology for repairing and improving the wear resistance of lathe tool slideways. The lathe slideway is a crucial component that determines the accuracy of parts during machining, requiring high durability and good wear resistance. WC-Ni material was chosen for its superior mechanical properties and durability. Before applying the coating to the product, the WC-Ni coating was created on samples with a substrate material similar to the product using plasma spray technology. The samples were then evaluated for properties such as adhesion strength, hardness, and wear resistance of the coating through standard testing methods. The spraying parameters included a current intensity of I = 678.9A, a powder feed rate of m = 30.8g/min, and a spraying distance of L = 159.3mm, applied to both test samples and products. The results showed that the WC-Ni coating applied using plasma spray technology significantly improved the wear resistance of the slideways, thereby considerably increasing the lifespan and performance of the lathe.

Keywords: *Plasma thermal spraying; WC-Ni coating; restoration; lathe slideways.*

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1. INTRODUCTION

During operation, machining machines that use slideways as guides for movement experience significant degradation over time, leading to damage. This deterioration is primarily caused by frictional forces. The slideways of lathe tool carriages are particularly susceptible to wear, as they endure intense friction between two contact surfaces, often exacerbated by hard particles generated during operation and external contaminants. This wear not only affects the accuracy of machined parts but also reduces the machine's performance and increases repair costs [1]. To restore and repair such damaged slideways, common methods in Vietnam include scraping and then lowering related parts and assemblies to fit, or flat grinding followed by applying Teflon to the slideways. Both restoration methods often result in surfaces with limited lifespan and sometimes lack stability during operation. In recent years, thermal spraying has attracted many scientists and material engineers in Vietnam to research and apply it to the surfaces of mechanical parts to enhance their working life. Thermal coatings created by various techniques such as HVOF, plasma, and arc spraying have been experimentally applied to restore certain types of damaged surfaces of shafts, bushings, and plates. Among thermal spraying techniques, plasma spraying is widely used due to its advantages of being applicable to most high-melting-point materials, producing coatings with low porosity and high adhesion to the substrate [2-6].

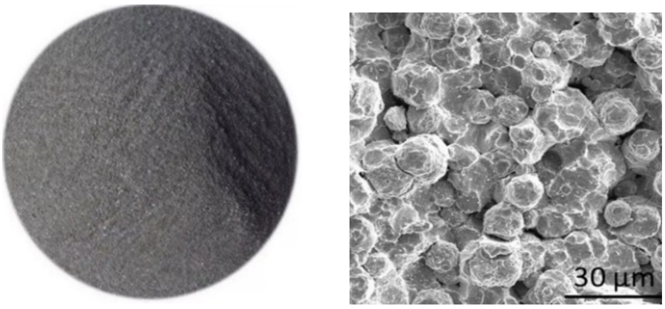
The coating material is a crucial factor determining the characteristics of the coating for specific applications. WC-Ni powder has been widely researched and applied in practice to create surface protective layers against abrasive agents caused by friction [7-11]. WC-Ni powder is a multi-element mixture, with each element playing a specific role in the formation of the coating. WC and Ni are the two main elements, accounting for a high proportion and playing important roles. WC contributes to the hardness of the coating, while Ni is an ideal binder that helps create a network of bonds between particles, forming a strong cohesive coating [12, 13]. Currently, a significant number of studies have created WC-Ni coatings on various steel surfaces, showing that the protective coating enhances erosion, corrosion, and wear resistance much better than the original performance of the substrate material. Specifically, D. Xie et al. conducted a study creating a technical ceramic coating combined with a WC-based coating, and the experimental results showed that the coating significantly reduced friction and wear, especially under lubricated conditions [14]. Furthermore, another study by Sun et al. indicated that WC-based coatings exhibited excellent performance with a low friction coefficient of 0.12 and a wear rate of 6.2×10^{-8} (mm^3/N.m) [15]. Other studies have also demonstrated that surfaces reinforced and protected with WC-Co or WC-Ni coatings not only increase hardness to improve wear life but also capture debris particles of 5 µm size and form a stable lubricating film, achieving a friction reduction efficiency of up to 20.9% [16-18]. This type of coating was also mentioned in a study by Zhang et al., which reported that the coating reduced the friction coefficient from 0.301 to 0.275 under dry friction conditions [19]. Therefore, researching and developing methods to improve wear resistance for machine parts and components is very important.

These findings highlight the importance of developing advanced methods to improve wear resistance in machine components. The research suggests that WC-Ni coatings offer an effective solution for restoring and enhancing the durability of mechanical surfaces, making them suitable for practical applications in Vietnam. Plasma spraying technology is an advanced method for restoring and extending the service life of components by generating high temperatures and pressures to form a protective coating layer. This coating improves wear resistance, corrosion resistance, and surface hardness. In this study, WC-45Ni (Tungsten Carbide-Nickel) material was chosen for its superior mechanical strength and excellent wear resistance. The research objective is to develop a process and evaluate the effectiveness of applying plasma spray coating technology to create a WC-45Ni coating on the slideways of lathe tool posts. This aims to restore shape and dimensions, enhance working capability, and extend the lifespan of the components.

2. MATERIALS AND DEVICE

2.1. Coating Material

WC - Ni powder (Hoganas - Belgium) is chosen for use in this study, WC - Ni particles have a size $-20+10^{6}$µm (Fig. 1), chemical composition: C ≤ 2.1%, Cr ≤ 10.05%, Ni ≤ 45.05%, Si ≤ 3.25%, Fe ≤ 3.05%, B≤ 2.25% and the remaining is WC.



a) Photo of WC-Ni coating powder b) Structure of WC-Ni powder

Fig. 1. Image and structure of WC - Ni powder

2.2. Coating Equipment and Process Parameters

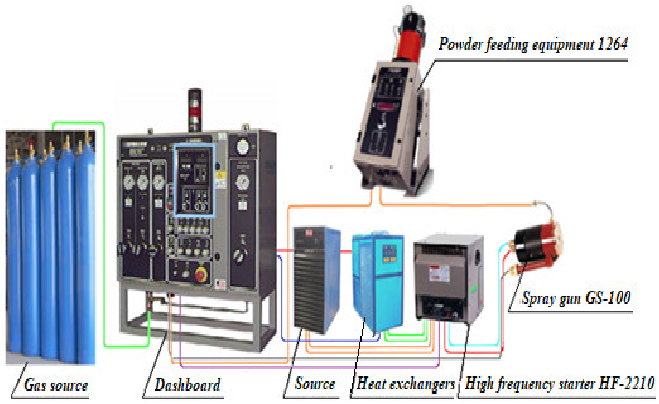


Fig. 2. Plasma spraying system 3710-PRAXAIR-TAFA

The spraying process is carried out on plasma spraying system 3710-PRAXAIR-TAFA (USA) with spray gun SG-100 (Fig. 2), the coating thickness after the process is ($1_0^{+0.2}$ mm). During the coating process, to ensure that the spraying distance remains unchanged throughout the operation and to achieve a uniform coating on both the sample surface and the sliding surface of the tool carriage, the research team utilized the AX-V50 Robot, a six-axis robot with a vertical joint configuration.

The spraying parameters were adjusted according to Table 1. These technological parameters were experimentally studied and evaluated on standard samples, and the results demonstrated that the WC-45Ni coating exhibits excellent properties, meeting the requirements for hardness, wear resistance, and strong adhesion to the gray cast iron (FC300) substrate.

Table 1. Plasma Spraying Parameters

Parameter	Value
Spray current (I_p)	678.9 (A)
Voltage (U_p)	35 (V)
Primary gas flow (P_{Ar})	50 (l/phút)
Secondary gas flow (P_{H2})	5 (l/phút)
Powder carrier gas (P_{Ar})	40 (l/phút)
Spray distance (l_p)	159.3 (mm)
Powder feed rate (m_b)	30.8 (g/phút)
Spray angle (γ_p)	60^0 và $90^0 \pm 5^0$

2.3. Coating Sample and Coated Details

- *Coating sample:* Gray cast iron (FC300) is used as the base metal material, the steel has the composition and ratio of elements including: C 3.5%, Si 3.0%, Mn 0.6%, P 0.1%, S 0.12%, the rest is Fe metal. The test sample is manufactured according to JIS-H-8664 standard, the surface of the coated sample was cleaned and roughened with a shot blasting machine, the roughness of the sample was (Rz ~ 71μm) [20].

- *Lathe Tool Carriage Slide:* The tool carriage slide is a crucial component in a lathe system, primarily responsible for holding and guiding the cutting tool during machining, ensuring stability and precision. To maintain operational efficiency, the tool carriage must exhibit superior mechanical properties, such as high hardness, wear resistance, and vibration damping, which significantly influence machining quality and the overall durability of the lathe.

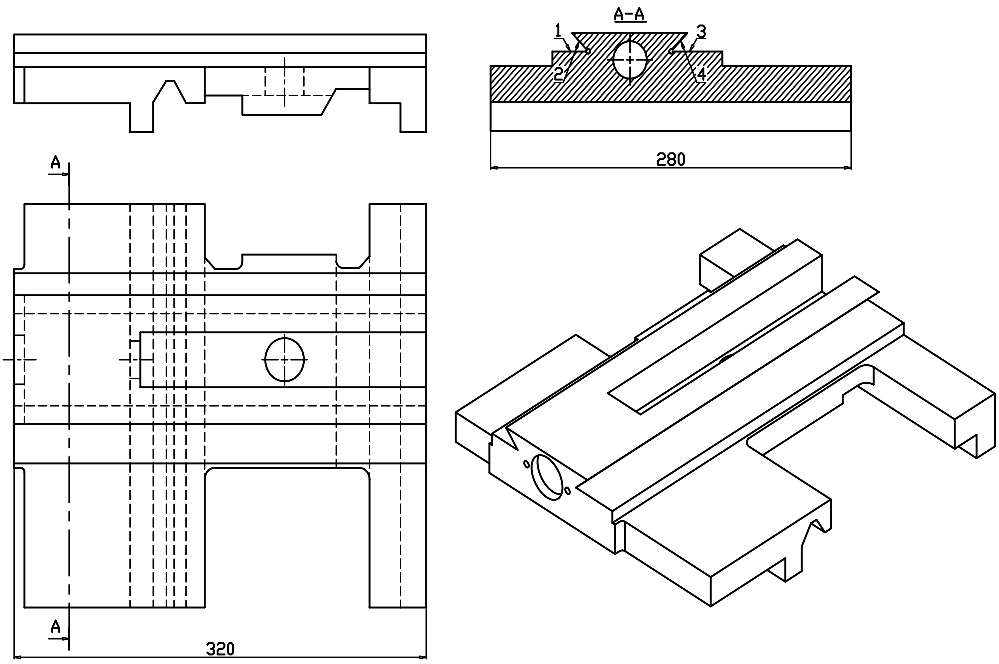


Fig. 3. Structural Drawing of the Longitudinal Lathe Carriage Slide

Typically, lathe tool carriage slides are made from gray cast iron, with structural design and dimensions tailored to each machine type. In this specific application, the restored tool carriage slide has dimensions of 320 × 280mm. The upper sliding surfaces of the longitudinal tool post support and guide the cross tool post during movement in machining. After a period of operation, the contact surfaces (Surfaces 1, 2, 3 and 4) become worn and damaged Fig. 3.

3. RESULTS AND DISCUSSION

3.1. Experimental Results on the Sample

Table 2. Optimization results of input parameters and objective function values

Output criteria	Objective	Value when optimizing			Predicted result
		I_p (A)	m_p (g/ph)	L_p (mm)	
τ_{Lp} (MPa)	Maximum	678.9	30.8	159.3	51.8
K_{Lp} (HV)	Maximum				732.3
I_{Lp} (g/N.mm)	Minimum				1.854×10^{-9}

The coating restoration process aims to protect the working surface of the lathe tool carriage slide. Therefore, the sliding surface must meet multiple quality criteria. Based on the quality requirements and working conditions of the lathe slideways, it is evident that the optimal multi-objective spraying parameters have been determined through standard samples. The goal is for the adhesion strength (τ_{Lp}) and microhardness of the coating (K_{Lp}) to be as high as possible, while the wear intensity (I_{Lp}) should be as low as possible. The optimization results of the multi-objective function for the parameters are summarized in Table 2, with an expected value of (D = 99,26%), indicating high reliability of the obtained parameters.

To evaluate the suitability of the obtained parameters when solving the multi-objective optimization problem, experimental

Table 3. Experimental validation results of optimal spraying values

Output criteria	Objective	Value when optimizing			Predicted result	Verified result	Deviation (%)
		I_p (A)	m_p (g/ph)	L_p (mm)			
τ_{Lp} (MPa)	Maximum	678.9	30.8	159.3	51.8	50.7	2.1
K_{Lp} (HV)	Maximum				732.3	712.8	2.7
I_{Lp} (g/N.mm)	Minimum				1.854×10^{-9}	1.915×10^{-9}	3.3

verification was conducted before applying the coating to the product. Each objective function was tested on 5 samples, with the spraying regime following the parameters in Table 1. The experimental verification results are the average values of the 5 measured samples, as summarized and presented in Table 3. Comparing the experimental results of all objective functions, it is observed that they are very close to the predicted results, with the adhesion strength objective function having the smallest deviation (2.1%) and the wear intensity objective function having the largest deviation (3.3%). The comparison results indicate that the spraying parameters (I_p, m_p và L_p) are suitable for practical application.

The objective function results presented in Table 3 show that the WC-45Ni material selected for fabricating the coating to restore the worn working surface of the tool slide using plasma spraying technology has demonstrated superior performance compared to the original tool slide material. Specifically, the conventional lathe tool slide is made by casting gray cast iron (FC300), which has a hardness range of 180 to 250HV, a wear rate of about 5×10^{-9}g/N.mm, and a tensile strength between 200 and 300MPa. However, previous studies have indicated that for sliding work surfaces subject to wear from friction, a coating with a sliding adhesion strength of at least 25MPa is sufficient to ensure stable working performance. Therefore, the WC-45Ni coating not only improves wear resistance but also meets the adhesion strength requirements under real working conditions.

3.2. Process and Results of Restoration on the Product

After evaluating the coating on the sample and confirming that it meets the technical requirements, the coating technology process was applied to restore the sliding surfaces of the lathe tool carriage slide. The procedure was carried out in the following steps, yielding the results outlined below:

Step 1. Preparation:

- *Coating material:* WC-45Ni powder was dried at 100°C to 150°C for approximately 12 hours before spraying to remove any residual moisture Fig. 1.

- *Coating equipment:* The Praxair plasma spray coating system was checked and prepared to ensure stable operation Fig. 2.

- *Lathe tool carriage slide:* The slide was disassembled from the machine, cleaned, and then machined to flatten the damaged slideway surface (the dovetail angle of the tool post was milled with a 60° carbide milling cutter). This machining step ensures that the working surfaces are on the same plane, facilitating control of the coating thickness during and after spraying Fig. 4a.

Step 2. Surface Roughening: The sliding surface was roughened using a Shang-Po abrasive blasting machine, achieving a roughness of Rz = 71 ± 2µm. After roughening, the surface was cleaned with dry air and immediately coated to prevent contamination and oxidation Fig. 4b.

Step 3. Mounting the Slide and Spray Gun: To ensure parameters such as spraying distance, movement speed, and spray angle remain stable throughout the spraying process, a 6-axis AX-V50 robot was used to mount the spray gun, and the tool post was fixed on a jig to ensure stability during coating Fig. 4c.

Step 4. Setting Spray Parameters: The plasma spraying parameters were configured according to the optimized values specified in Table 1.

Step 5. Preheating: Preheating was carried out by directing the spray gun flame onto the surface, raising the temperature to 140°C to 150°C. The temperature was monitored using an OPTEX PT-7LD infrared thermometer.

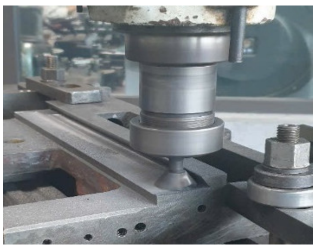
Step 6. Coating Application: Once the surface reached the preheating temperature, the powder feed valve was opened, and the coating process was initiated. The minimum coating thickness applied to each surface was 1.2 mm Fig. 4c.

Step 7. Post-Coating Machining: The working surfaces of the tool post after coating need to be machined to ensure flatness, coplanarity, and a 60° angle. Due to the high hardness of the WC-45Ni coating, a suitable machining method was chosen to avoid affecting the coating quality. In this study, the coating surface was machined using a grinding wheel on a milling machine, with a 60° carbide grinding wheel Fig. 4d.

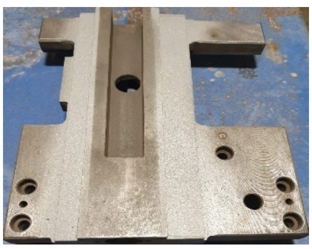
Step 8. Inspection and Evaluation: After machining, the coating quality on the lathe tool carriage slide surfaces was inspected and evaluated using microhardness testing with an ISOSCAN HV2 AC device Fig. 4e. The hardness measurements taken at five different positions on each coated surface ranged between 706HV and 715HV, closely matching the values obtained from the standard test samples. This confirmed the stability and reliability of the coating process and parameters.

Step 9. Assembly and Performance Testing: After being coated and finished, the lathe tool slide was put into actual production operation at Logarit Vietnam Joint Stock Company for a period of 12 months. The lathe using the restored tool slide is a small-sized lathe, operating at an average intensity of about 5 to 6 hours per day. It is estimated that the total operating time of the machine over the 12 months is approximately 1600 hours. Due to the limited machining capacity of the machine, the processed workpieces are generally not large. Therefore, the cutting force acting on the tool and the tool slide in the main cutting direction is determined to average around 1300N.

Following installation and commissioning, the research team conducted three periodic inspections at four-month intervals. The results showed stable operation and positive feedback from machine operators. Specifically, after applying the WC-45Ni coating, operators noted that the handwheel operation became smoother, and the machining accuracy remained consistent, both in manual and automatic modes, compared to similar machines using original manufacturer sliding surfaces.



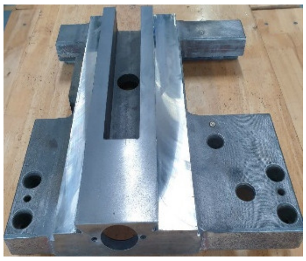
a) Machining the worn working surfaces



b) Roughening the coating surface

c) Applying the coating to the working surfaces

d) Machining the surfaces after coating



e) Machine knife table after grinding flat

f) Assembly, inspection and commissioning

Fig. 4. Images of the basic steps in the lathe tool carriage restoration process

4. CONCLUSION

This paper conducts experimental researchto establish a process for restoring the worn sliding surfaces of lathe tool carriages using WC-45Ni plasma thermal spray coatings to improve the surface quality and service life of the carriage surfaces after restoration. The results obtained after testing on standard samples and subsequently applying the restoration process to the lathe tool carriage sliding surfaces for real-world production activities after 12 months are as follows:

1. Successfully created a WC-45Ni coating on gray cast iron (FC300). The validation results for three criteria show a sliding bond strength of 50.7MPa, an average hardness of 712.8HV, and a wear intensity of 1.915 x 10^{-9}g/N.mm.

2. Developed a process to restore products by plasma spraying WC-45Ni coatings. The process was successfully applied to restore the four working sliding surfaces of lathe tool carriages for Logarit Vietnam Joint Stock Company. After 12 months of real-world production conditions at the company, the coating has not delaminated or deteriorated. The coating demonstrated excellent wear and erosion resistance, meeting practical working requirements.

3. The method of restoring working sliding surfaces with WC-45Ni coatings using plasma spraying is highly effective and can be widely applied to restore other damaged surfaces and mechanical components in industrial applications, providing economic benefits. This is also a direction for future research and application.

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