Research Progress in Mechanical and Manufacturing Engineering Vol. 2 No. 2 (2021) 121-129

RPMME

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

A Review of Wear and Corrosion for Carbide-Coating on Different Method: HVOF Thermal Spray and Electrodeposition Method

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DOI: https://doi.org/10.30880/rpmme.2021.02.02.015
Received 02 Aug. 2021; Accepted 27 Nov. 2021; Available online 25 December 2021

Abstract: This study is focused on carbide-coating with different types of methods. The method involved in this study is between the High-Velocity Oxy-fuel (HVOF) thermal spray method and the electrodeposition method. In order to improve the material surface properties such as hardness, wear and corrosion, both methods are conducted. In this study, the substrate used is carbon steel and was placed at the cathode for the electrodeposition process. AISI 1040 carbon steel also have been used as a substrate for HVOF thermal spray carbide coating. The parameter for each method, for electrodeposition method, used 50°C of Watts bath temperature and 0.5 A/cm² for current density, where for HVOF thermal spray is 45 LPM oxygen flowrate. The objective of this study is to compare the wear behavior, hardness, and corrosion-resistant of both carbide coating methods. To compare the surface morphology, both methods have been analyzed using Scanning Electron Microscope no significant difference was shown on the surfaces. X-ray diffraction method was used to identify the phase analysis where both methods. Both methods have the same element present but different in peak and amount of element. In wear testing, hardness testing, and corrosion analysis, HVOF thermal spray samples show higher value results compare to electrodeposited samples.

Keywords: Carbide Coating, HVOF Thermal Spray, Electrodeposition

1. Introduction

Tungsten Carbide with its wide variety of compositions finds comprehensive applications in the industries like cutting tools, wear parts, mold and die, due to their superior tailor-made properties such as combined perfect hardness-toughness, thermal shock absorption, abrasive, and wear resistance [1]. Wear is a common phenomenon in parts having relative velocities where during wear the metallic

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particles are removed from the surfaces and commonly found in different mechanical components [2]. HVOF spray is especially well suited for the deposition of cermet materials such as WC-Ni and WC-Co to solve wear and corrosion issues. This is a consequence of the higher particle velocities with the relatively lower particle temperatures obtained with HVOF compared to the other thermal spraying processes [3]. Electroplating is one of the methods that also protect agzainst wear and corrosion. Electroplating is an electrodeposition process of producing a coating on a surface by the action of electric current [4].

The demand for high wear and corrosion resistance components in various industries is increasing all the time. Many industries faced the same issue, which was that the surface of components where it was subjected to deterioration, wear, and corrosion. This study was designed to investigate the most suitable coating method to increase wear and corrosion resistance by using an appropriate method which is the High-Velocity Oxy-fuel (HVOF) thermal spraying and electrodeposition method.

The objectives of this study are to compare the wear behavior of HVOF coating and electrodeposition coating. Next is to identify the effect of carbide size on the wear behavior of both coating methods. Lastly, the objective is to compare corrosion rate and hardness of carbide coating for the different methods which are the HVOF spray method and electrodeposition method.

2. Materials and Methods

The following are materials and methods for preparing for the HVOF thermal spray sample and electrodeposition sample.

2.1 Materials

Material preparation for HVOF thermal spray samples is AISI 1040 carbon steel used as substrate and WC-10Ni powder as the medium for the spray method. For the electrodeposition process, the materials are as shown in Table 1.

Table 1: Materials preparation for electrodeposition method (Watts' bath)

Item	Amount
Nickel Sulphate	200 g/l
Nickel Chloride	20 g/l
Boric Acid	20 g/l
Current Density	0.5 A/cm²
Bath Temperature	50ºC

2.2 Methods

The sample preparation for HVOF thermal spray was prepared and ready for the tests. Firstly, the carbon steel plate was thoroughly cleaned with solvent to remove mill, rust scale, and dirt. A chemical solvent is used to remove oil, grease, and paint. The carbon steel is subjected to grit blasting using aluminium oxide, which is a traditional process also known as sandblasting. It is necessary to prepare the surface for the high-performance coating to achieve the desired luster and texture. Another reason for this procedure is to improve the bonding of the spray powder (coating) with the substrate (base steel) [5]. While the machine is turned off, aluminium oxide is loaded. The unit is then plugged in and charged. When the trigger on a nozzle is released, aluminium oxide shoots out at high speed with a working pressure of 70 psi – 100 psi. It is directed at the metal piece that will be grit blasted. To avoid settling in one area of the piece, the nozzle will be moved back and forth [5]. The HVOF spray machine was ready after the grit blasting was finished. The diamond jet (Sulzer Metco) was used to spray the powder at high speed (700 m/s), resulting in a hard, dense, and porous-free surface. The parameter is determined by the type of powder used, which in this case is WC-10Ni. Oxygen and compressed natural gas are the

gases used in this process (CNG) [5]. During the powder preheating process, it reacts with the other chemical group of the powder to polymerize and improve the performance properties. After preheating the powder, it was loaded into the machine's container. The metal substrate will then be sprayed with the diamond jet after the machine has been set up. The sample is then allowed to cool to room temperature. Estimated temperature range of 900 °C to 1050°C [5].

For the electrodeposition process, the sample will be cut into a 10mm x 10mm x 10mm by using EDM wire-cut. For preparation Watt's Bath is used as an electrolyte which contains 20 g/L of WC and a current density of 0.5 A/cm². Carbon steel and Nickel plate have been used in the experiment to act as an electrode. The beaker was used to fill the electrolyte solution during the electrodeposition process, while the wire clippers were used to connect the current from the power supply. The wire clippers also held the anode and cathode in place while they were immersed in an electrolyte solution. All deposition studies were powered by a DC-regulated power supply. The parameters were used to calculate the current rate from the power supply. A magnetic stirrer was among the other pieces of equipment used. To keep the dispersed particles in suspension, magnetic stirring was used as an automatic stirrer for the electrolyte solution at scale 2 at a speed of 160rpm. Before the test, some equipment, such as the beaker, cathode terminals, and anode terminals, were cleaned and washed with distilled water. As a precaution, the rod holder is used to keep the wire clippers from being submerged in the electrolyte solution. Figure 1 shows the schematic diagram of the experiment.

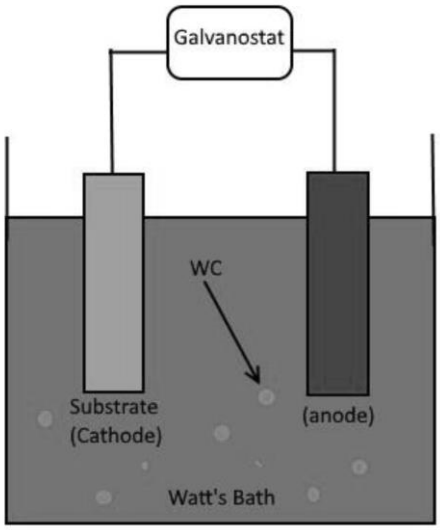

Figure 1: Schematic diagram of deposition arrangement [6]

2.3 Wear test

In this study, the wear behaviour of the coating was evaluated using the weight loss method. Forcipol 2V Grinder-Polisher was used in this analysis. The sample tested was cleaned thoroughly before the test started and the weight of the material has taken for both before and after the wear test. During the test, the stainless-steel plate was used with a 3 g/l concentration of silicon carbide as the abrasive material.

2.4 Corrosion test

For corrosion studies, the test was conducted by immersing the sample in a solution containing 0.5M sulfuric acid. An immersion test was conducted to identify the corrosion rate of the exposed surface area of the coating. The sample then being monitored every 72 hours in order to examine the

corrosion that existed on the coating after the immersion. The weight of the sample has been taken both before and after the immersion process. This procedure was being utilized to determine the weight loss due to corrosion. Other than that, surface analysis can be performed by scanning electron microscope to further investigate the morphology. For determining the rate of corrosion of every sample, the corrosion rate formula has been used:

$$Corrosion\ Rate, CR = \frac{87.6W}{DAT} \quad \text{Eq. 1}$$

Where W is mass loss (g), D is the density of metal coating (g/cm³), A is the area of corrosion (cm³) and T is the time of immersion (h).

3. Results and Discussion

The result was obtained for both the HVOF method and electrodeposition method of WC-Ni and comparing both methods that coated on carbon steel. The result consists of the characteristic of coating, hardness test, corrosion test, and wear test.

3.1 Surface morphology of both coatings

The Scanning Electron Microscope (SEM) with Energy Dispersive Spectroscopy (EDS) and X-Ray Diffraction is used to examine surface morphologies and microstructure, coating thickness, and phase identification (XRD). Figure 2 shows the morphology of both coatings.

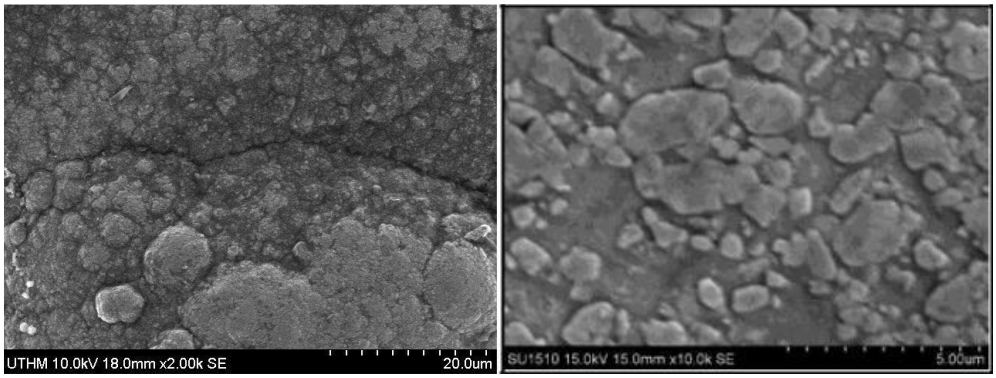

Figure 2: Surface structure for electrodeposited (left) [7] and HVOF thermal spray sample (right) [5]

From the figure, the structure for both samples was nearly the same. Both show a rough and clear structure of deposited WC-Ni. Looking forward to the element and amount that are present in the coating. Tables 2 and 3 show elements present in the method respectively.

Table 2: Existing element in HVOF thermal spray [5]

XRD	Existing element
Sample A (30 oxygen flowrate)	Ni, WC, W_2C, O
Sample B (45 oxygen flowrate)	Ni, WC, W_2C, O
Sample C (60 oxygen flowrate)	Ni, WC, W_2C, O

Table 3: Element percentage on 50°C and 0.5 A/cm² [6]

Element	Weight%	Atomic%
C K	12.12	42.53
Ni K	76.38	54.83
W M	11.50	2.64
Totals	100.00	

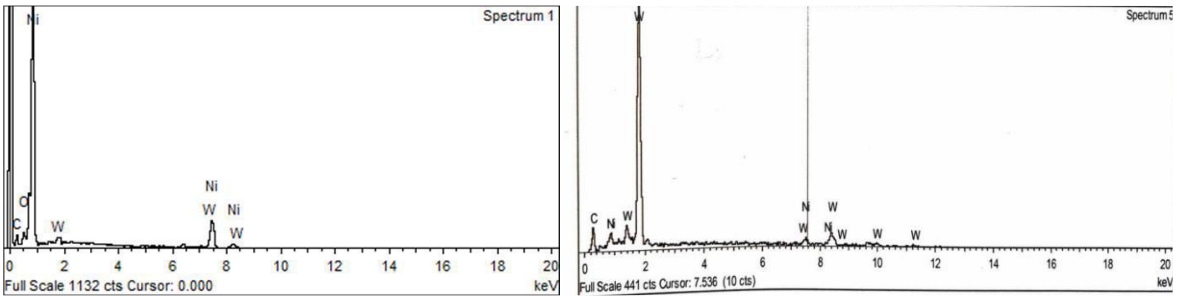

Figure 3: Graph of Point Spectrum for electrodeposited (left) [6] and HVOF sample (right) [5]

Based on the SEM micrograph of the surfaces of both samples of the HVOF method and electrodeposition method, HVOF spray samples shows the element of W is higher compared to electrodeposited samples that show Ni element. Both samples show that both Ni and W elements are present in the coating process but different in content.

3.2 Coating thickness analysis

The coating thickness was measured using an optical microscope. The thickness of the coating for each sample is shown in Figure 4.

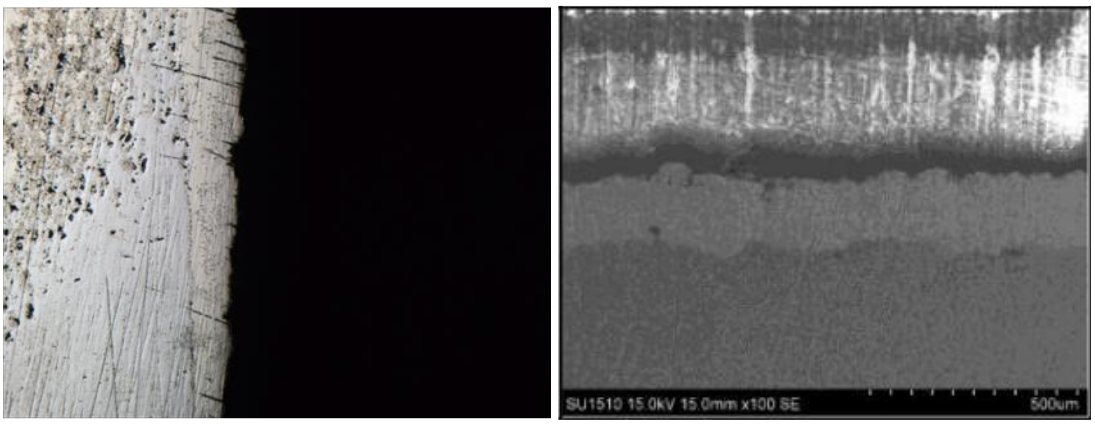

Figure 4 Coating thickness for electrodeposited samples (left) [7] and HVOF samples (right) [5]

From the SEM image obtained, the results show that coating thickness for the electrodeposition method is thinner compared to the coating thickness of the HVOF spray method. HVOF thermal spray samples give uniform coating thickness as it is sprayed at the same velocity at a uniform surface. The electrodeposition process may not be uniformly coated as it involves the transfer of ions in an electrolyte

3.3 Phase analysis

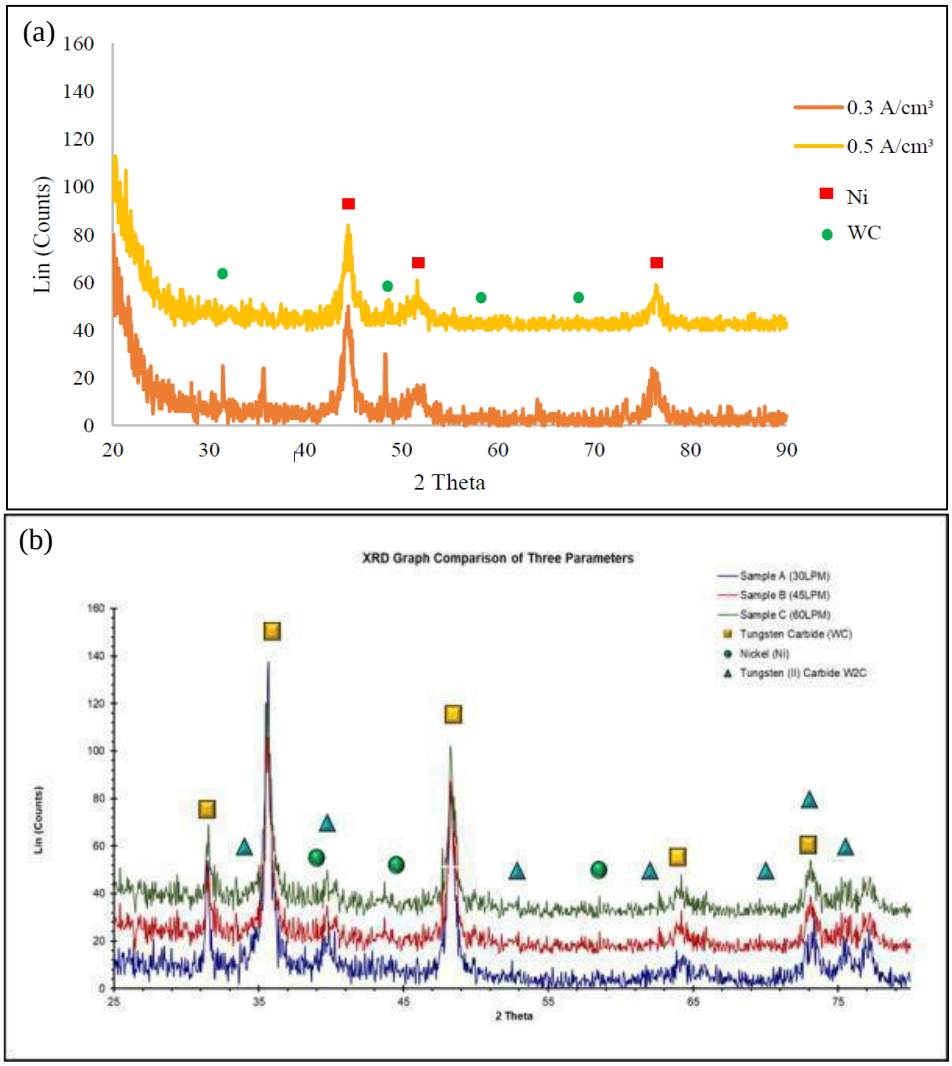

Figure 5: XRD analysis for (a) electrodeposited samples [7] and (b) HVOF samples [5]

From the graph obtained, the XRD pattern for both samples shows a peak at WC and Ni elements. It is also found that there are no changes in the element present in the coating although the parameter has been altered in HVOF thermal spray samples. However, the parameter for electrodeposition which give different peak for different current density. It can be concluded that current density influences the number of elements in a coating process.

3.4 Coating hardness analysis

Following the surface morphology and coating phase analysis of the samples, the microhardness of the coating for all samples was examined using an HMV-2 Shimadzu Microhardness Tester. Table 4 shows the average hardness for electrodeposited samples where Table 5 shows the average hardness number for HVOF spray method.

Table 4: Average microhardness number (HV) for electrodeposition samples [7]

Samples	Average Microhardness Number (HV)
30S0.3A	342.356
30S0.5A	448.646
50S0.3A	351.881
50S0.5A	455.585

Table 5: Average microhardness number (HV) for HVOF samples [5]

Samples	Average Microhardness Number (HV)
Sample A (30 Oxygen flowrate)	575.5
Sample B (45 Oxygen flowrate)	668.3
Sample C (60 Oxygen flowrate	881.5

From the tables, the result taken for the electrodeposition process which is 50°C and 0.5 A/cm (50S0.5A), and for HVOF thermal spray, the result taken is for sample B (45 oxygen flowrate). The result is 455.585 HV for electrodeposited samples and 668.3 HV for HVOF spray samples. HVOF spray method gives higher strength where HVOF sample gives higher Microhardness Number (HV) compare to electrodeposited sample. This proves that HVOF thermal spray can resist higher plastic deformation compared to the electrodeposition method.

3.5 Wear behaviour analysis

Wear behavior of both electrodeposited samples and HVOF thermal spray samples were tested at a different sliding distance where electrodeposited samples were tested at 300 m while HVOF spray samples were tested until 1000 m sliding distance. The result obtained from the wear test were shown in Tables 6 and 7 respectively for each type of samples.

Table 6 Average weight loss for electrodeposited samples [7]

Samples	Average weight loss (g)
30S0.3A	0.1247
30S0.5A	0.0985
50S0.3A	0.1175
50S0.5A	0.0931

Table 6 Average weight loss for HVOF samples [5]

Sample	Initial Weight (g)	Weight after 1000m (g)	Average Weight Loss (g)
A1	14.7776	14.7483	
A2	16.1365	16.1146	0.002347
A3	13.6823	13.6416	
B1	14.6971	14.6875	
B2	14.6916	14.6743	0.002067
B3	16.1274	16.1077	
C1	15.7365	15.7331	
C2	16.0021	16.0003	0.01113
C3	14.9438	14.9376	

The result for HVOF samples was taken for samples B1, B2, and B3 where samples taken for electrodeposited is 50S0.5A (50°C and 0.5A/cm). The average weight loss was taken for both samples. Although HVOF spray samples were tested at a higher skidding distance, it still gives lower average weight loss. Lower average weight loss proves that the coating is more reliable and can withstand the higher load when induce to a load and wear.

3.6 Corrosion behaviour analysis

The immersion method was used to assess the corrosion behaviour of a WC-Ni composite coating. The corrosion rate was only found on the sample's exposed surface. Table 7 displays the results of the immersion test after every three days of immersion. Table 7 shows the reduction in sample weight for every three days of immersion. The rate of weight loss increased over time.

Table 7 Immersion test weight loss result for electrodeposition sample [7]

Sample	Weight before (g)	Weight after (g)				Total weight loss (g)	Corrosion Rate (mm/year)
		3 days	6 days	9 days	12 days		
30S0.3A	17.452	17.446	17.413	17.407	17.389	0.063	0.0026
30S0.5A	17.171	17.160	17.104	17.095	17.079	0.092	0.0038
50S0.3A	17.581	17.578	17.565	17.553	17.544	0.037	0.0015
50S0.5A	17.877	17.876	17.867	17.859	17.852	0.025	0.0010

4. Conclusion

In conclusion, this study has achieved the objectives. Both methods of carbide coating have shown their properties and performance in various testing which are hardness testing, wear behavior, and corrosion testing respectively. The study also met the objective to compare both carbide coating methods in terms of wear behaviour. The findings of this study have shown that the different methods used have contributed to the results and analysis. Higher hardness was seen in the HVOF coating than electrodeposition coating. With shorter distance electrodeposition coating shows higher weight loss showing the lower wear resistance of this coating compared to HVOF coating.

Acknowledgment

The authors wish to thank to the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia that has supported on the accomplishment of research activity.

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