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Influence of Deposition Parameter to Wear Behaviour of Tungsten Carbide-Nickel (WC-Ni) High Velocity Oxyfuel (HVOF) Coating

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Abstract: This study is done to investigate the influence of deposition parameter to the hardness and wear resistance of the tungsten carbide nickel (WC-Ni) High velocity oxy-fuel (HVOF) coating which is sprayed on the AISI 1040 medium carbon steel. Three different spraying parameters were used with the oxygen flowrate of each being changed and all other parameters and its value is kept constant. Oxygen flowrate of 30, 45 and 60 LPM were used. The result of hardness, wear rate and surface morphology were compared between the coatings. To compare the surface morphology of the three different parameter HVOF coatings, a scanning electron microscope was used. No significant changes shown on the surface of the coatings where all shows the same lump and crevices structure. X-ray diffraction was used to observe the elemental composition on the three coatings, all the coatings have the same elements present on them. It can be seen that all the coatings contains nickel, tungsten carbide, tungsten (II) carbide and oxygen. The method used for hardness test was the Vickers microhardness tester while weight loss test was used to study the wear resistance. Following the test, it is found that the hardness and wear resistance increased as the oxygen flowrate was increased. The highest hardness and wear resistance can be found in the coating with 60 LPM oxygen flowrate.

Keyword: High velocity oxy-fuel; tungsten carbide nickel coating; hardness; wear resistance.

1.0 Introduction

High Velocity Oxygen Fuel (HVOF) is a method generated to produce spraying with immense velocity. There are a few methods to achieve high velocity spraying such as using HVOF combustion chamber which have been high pressure water-cooled besides using long nozzle. The chamber is fed with fuel and oxygen, the combustion process produces a high temperature and pressurized flame which is forced down a nozzle which increases its velocity [1]. The HVOF coating are significantly dense, high strength and portrays low residual tensile stress and in some exceptional cases compressive stress, which allows the application of thicker coatings [2]. To produce a high quality HVOF coatings, it is not required for the particle to be in a fully molten state since the kinetic energy of particles that strikes the substrate surface is very high [3].

Generally, metallic materials are usually tended to easily exposed and liable to wear which are influenced by various working conditions such as chemical, electrochemical reactions as well as frictions. These failures will result in economic loss whether in small or big scale. Efforts are made by researchers to prevent or even reduce such outcome.

Therefore, amorphous alloy is made. Amorphous alloy is a material without crystalline structure. Some positive characteristics of amorphous alloy is its high hardness, superior corrosion resistance, good wear resistance and mainly because it is much more attractive, as well as low cost [4]. With this material, failure of parts could be eliminated, if not, delayed.

Although there are some amorphous form provides little or no improvement over crystalline material, the statement holds true for class of iron-based amorphous alloys. If the melt is cooled at a rate higher than the critical cooling rate, amorphous structure is formed [5].

HVOF coatings brings greater good than harm. Parameters of the HVOF spray includes

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carrier gas flow rate, spraying distance, a gun transverse speed and the powder feed rate. As seen from previous research made, the changing of oxygen flowrate also affected the hardness and wear behaviour afterwards [6]. The wear resistance will steadily increase as the oxygen flowrate is simultaneously increase [7]. With that, further study on the correlation of HVOF spraying parameters, hardness and wear behaviour was evaluated. Analysis and reports on its microstructure, microhardness, phase composition also wear resistance is obtained in relation with HVOF spraying parameters.

2.0 Materials and Methodology

In general, the WC-Ni coating samples have been tested to determine its behaviour and mechanism. Testing in this study includes wear test and Vickers microhardness test. Tests been run by using the modified grinding machine and Vickers microhardness test for wear test and hardness test respectively. Prior to spraying, substrate is blasted with sand and clean with acetone. For the HVOF spraying process, thermal spraying was carried out with high velocity oxyfuel spraying equipment. Spraying parameter were adjusted by varying the oxygen flowrate at 30, 40 and 60LPM.

2.1 Sample Preparation and Characterization

For this study, carbon steel was used as specimen. Since most tools and machineries used in the industry are made up of this material, hence it is the most suitable material to be used. The carbon steel is subjected to a lot of external forces, friction and other miscellaneous hence inducing increase in wear to the surface.

Thus, new alternatives are needed to increase the wear and resistance, which is to coat with HVOF thermal spray. Several procedures must be follow in performing HVOF thermal spray to achieve the desired product.

Firstly, the carbon steel plate was clean with solvent to remove mill, rust scale and dirt. To remove oil, grease and paint, chemical solvent is used. The carbon steel undergoes grit blasting process by using aluminum oxide, it is a conventional process and sometimes also known as sand blasting. The grit blasting machine used is as shown in Fig.1. It is an important process to prepare the surface for high performance coating, to give the surface a desired luster and texture. Another reason to do this process is so that the spray powder (coating) bond with the substrate (base steel) more efficiently.

Aluminum oxide is loaded while the machine is off. Then, the unit is plugged in and charged. An air tank provides the propellant force for the blasting process; a gauge is embedded to the tank where it will show when the air has reached a sufficient pressure. Fig. 2 shows the grit blasting machine.

Fig. 1 Grit Blasting Machine, Empire, USA

After the machine is set up, both the air and aluminum oxide valves will be open. A nozzle handled with a trigger, when the trigger is released, the aluminum oxide shoots from it at high speed with a working pressure of 70 psi – 100 psi. It is directed to the metal piece to be grit blasted. The nozzle will be move back and forth to prevent settling in one area of the piece.

After grit blasting is completed, the HVOF spray machine were prepared. The diamond jet (Sulzer Metco) was used to spray the powder at high speed (700 m/s), the result would be a hard, dense and porous free characteristic. The parameter is set based on the type of powder use and in this case, WC-10Ni. Gasses used in this process is oxygen and compressed natural gas (CNG).

During the powder preheating, it reacts with the other chemical group of the powder to polymerize and improve the performance properties. After the powder is preheated, the powder was loaded into the container of the machine.

Next, after the machine is set up, the metal substrate will be sprayed with the diamond jet. Sample is then left to cool down to room temperature. Estimation of 900 °C down to 50 °C. The steps are repeated by changing the parameter of the oxygen flow rate as in Table 1. The parameter of the coating is altered based on the particle size of the powder. Table 2 shows the parameter used for the HVOF spraying for WC-10Ni coating.

Table 1 HVOF Thermal Spraying Parameter Change.

Parameter		1st Setting	2nd Setting	3rd Setting
Flow	Oxygen	30	45	60

Table 2 Parameter of HVOF Thermal Spray (Metco,2006).

Coating Material		WC-10Ni
Particle Size (µm)		45±11
Pressure (bar)	Oxygen Press	10.3
	Fuel Press	7.6
	Air Press	7.2
Flowmeter Reading (F.M.K)	Oxygen	30
	Fuel	62
	Air	40
Flow (NLPM)	Oxygen	190
	Fuel	202
	Air	320
Powder Feeder	N_2 (FMR)	55
	N_2 Flow (NLPM)	12.5
	Air Vibration (bar)	1.4
Spray	Rate (g/min)	38-75
	Distance (mm)	250
	Deposit eff (%)	55

After spraying, the carbon steel substrate is cut into small dimensions of (10mm x 10mm) by using electric discharge machining (EDM) wire cut. The samples are then mounted followed by grinding and polishing in order to observe the microstructure of the coating.

The phase and characterisation analysis were evaluated by using x-ray diffraction (XRD). The SEM was used to evaluate the morphology as well as the coating thickness.

2.2 Hardness and Wear Test

Coating hardness have been evaluated by the Vickers micro-hardness tester as shown in Fig. 2. The measurement is carried out under indention loads of 0.05 HV (490.3Mn) within 10s according to ASTM E384.

Fig. 2 Vickers Micro-Hardness Tester Shimadzu, Japan

The weight loss method (mass) is a method that is easy to detect and analyse the wear rate of a material, especially when the surface of the wear material is not regular and not symmetry. Sample tested is cleaned thoroughly, the weight of the material was taken both before and after the wear test. The test was conducted by using the modified METCON grinder and polishing machine (Figure 3) with a varying distance of 1000m, 2000m, 3000m and 4000m.

Prior to testing, the sample is mounted to the holder of the machine with 20N of applied force. Speed of 200rpm is used for the wear track as well as the pump speed that supply the silicon carbide (SiC) slurry.

For each sliding distance, the time taken to complete the cycle is 18 minutes since the radius of the base (stainless steel) is 0.045m. The total time taken for each distance is shown in Table 3.

Fig. 3 Modified Grinder Machine Metkon, Turkey

Table 3 Time Taken for Each Sliding Distance

Distance (m)	Radius (m)	One Cycle Distance (2πr) (m)
1000	0.045	0.2827
2000	0.045	0.2827
3000	0.045	0.2827
4000	0.045	0.2827

Number of Cycle	Speed (rpm)	Time (min)
3536.7765	200	17.68388587 ≈ 18
7073.5530	200	35.36776513 ≈ 35
10610.3295	200	53.0516477 ≈ 53
14147.1061	200	70.73553026 ≈ 71

3.0 Result and Discussion

Results of hardness test and wear test for AISI 1040 medium carbon steel which has been sprayed with three different parameters of WC-Ni High Velocity Oxyfuel (HVOF) coating were evaluated. The microstructure was analysed and discussed as well.

These analyses are made to determine the comparison between the three different spraying parameters on the medium carbon steel substrate.

3.1 Morphological Observations of Sample

Three samples were prepared, each with different parameters, had undergone SEM observations to differentiate and observe the surface composition and microstructure for the coatings of the samples. Two different images were taken for each sample, the backscattered electron image (BSE) and the Secondary Electron image (SE). The surface morphology is shown from Fig. 5 to Fig. 7, while Fig. 4 below shows the cross sectional view of the coating thickness.

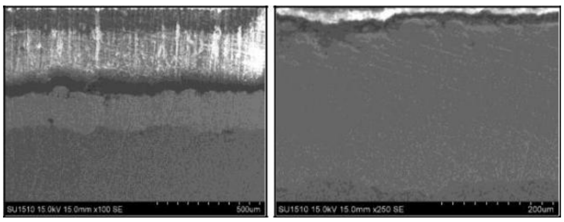

Fig. 4 Cross-section View of the Coated Sample

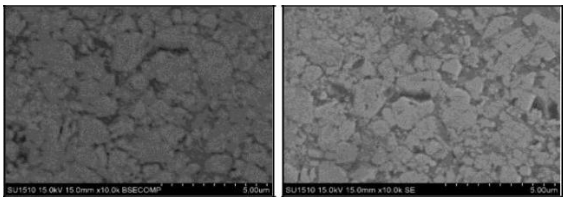

Fig. 5 Surface Morphology for HVOF Coating with 30LPM Oxygen Flowrate. Image (Left) and SE Image (Right)

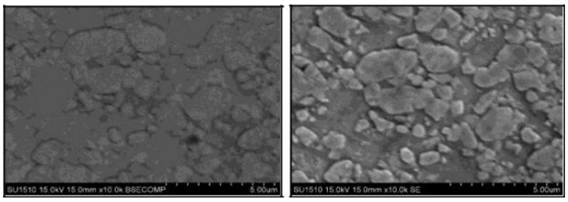

Fig. 6 Surface Morphology for HVOF Coating with 45LPM Oxygen Flowrate. BSE Image (Left) and SE Image (Right)

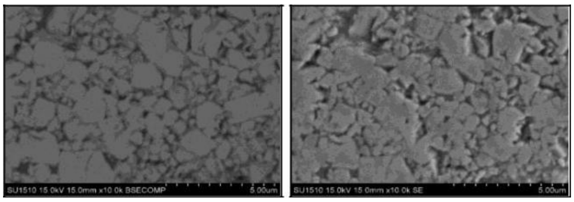

Fig. 7 Surface Morphology for HVOF Coating with 60LPM Oxygen Flowrate. BSE Image (Left) and SE Image (Right)

Based on the SEM micrographs of the surface of the three different samples with three different parameters of HVOF WC-Ni coating, all the surface of the individual samples shows the same morphology of lump and crevices. Their surface compositions are all almost the same.

3.2 Analysis of XRD

The results of XRD is as shown in Fig 8 below

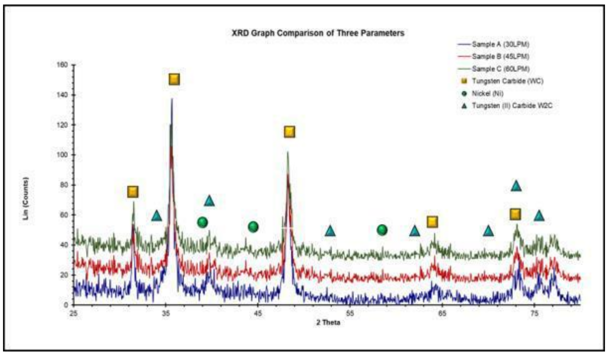

Fig. 8 Combined XRD Analysis of Three Different Parameters of HVOF Coating

After analysis is made, it is found that there are no changes in the elements present in the coating although a parameter has been altered. The elements present includes nickel, tungsten carbide, tungsten (II) carbide and oxygen. Table 4 shows the list of existing elements in the HVOF coatings.

Table 4 List of Existing Elements in Coatings

XRD	Existing Element			
Sample A (30 Oxygen Flowrate)	Ni	WC	W2C	O
Sample B (45 Oxygen Flowrate)	Ni	WC	W2C	O
Sample C (60 Oxygen Flowrate)	Ni	WC	W2C	O

3.3 Analysis of Hardness Test

After the test was completed, the microhardness data is displayed on the screen. In order to get a more accurate result, 10 different readings were taken for each sample. Averages of the hardness are calculated and tabulated in Table 5 below.

Table 5 Average Hardness Number for Vickers Microhardness Test (490.3mN, 0.05HV Load)

Samples	Average
A (30 Oxygen Flowrate)	575.5
B (45 Oxygen Flowrate)	668.3
C (60 Oxygen Flowrate)	811.5

From the results tabulated in Table 5, the hardness value increases with increasing oxygen flowrate. The trend of changes in hardness between the three different parameters of spraying is clearly seen. The average Vickers hardness number of the HVOF coating with 30, 45 and 60LPM oxygen flowrate parameter sample are 575.5HV, 668.3HV and 811.5HV respectively.

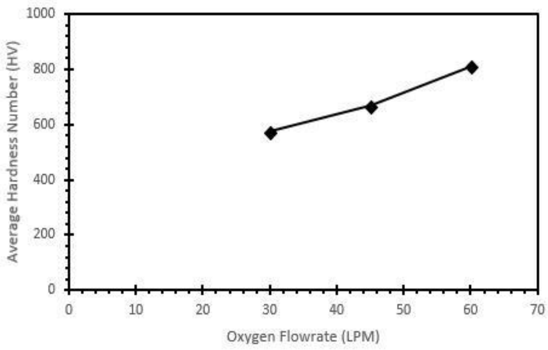

Fig. 9 Average Vickers Hardness Graph

Based on the graph shown in Fig. 9 the average hardness number increases with increasing value of oxygen flowrate. The highest hardness number is when the oxygen flowrate is 60LPM while the hardness number is the lowest when oxygen flowrate is 30LPM.

The result indicates that the hardness of the HVOF WC-Ni coating on the AISI 1040 medium carbon steel becomes harder as the oxygen flowrate of the spray is increased. It shows that a higher oxygen flowrate has higher hardness. This is because as the oxygen rate is increase, it creates a higher oxygen to fuel ratios or stoichiometry [8].

This results in higher deposition rate; the porosity is also lowered. Hence higher Young’s modulus which then result in better hardness [9]. Thus, this result proving that by increasing the oxygen flowrate for the HVOF spray parameter would harden the material.

3.4 Analysis of Test

The average wear test result is shown in Fig. 10 below after the weight loss method is applied.

Table 6 Average Weight losses of three different parameters of HVOF coating

Sample	Initial Weight (g)	Weight After 1000m (g)	Average Weight Loss (g)
A1	14.7776	14.7483	0.02347
A2	16.1365	16.1146	
A3	13.6823	13.6416	
B1	14.6971	14.6875	0.02067
B2	14.6916	14.6743	
B3	16.1274	16.1077	
C1	15.7365	15.7331	0.01113
C2	16.0021	16.0003	
C3	14.9438	14.9376	

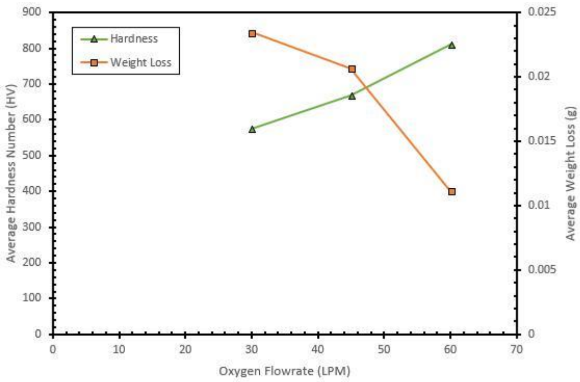

Fig. 10 Average Weight Loss of Three Different Parameters of HVOF Coating

From the data tabulated in Table 6, the average weight loss of Sample A which is the spraying parameter with 30LPM oxygen flowrate is 0.02347g, as for the parameter with 45LPM oxygen flowrate is 0.02067g and lastly the parameter with 60LPM oxygen flowrate has a weight loss of 0.01113g.

From the figure, it proved that the wear rate decreases as more oxygen is used in the spraying parameter.

Also, presented above shows the highest wear rate is from the samples which have the lowest oxygen flowrate, with flowrate of 30LPM. Clearly proving wear rate is directly influenced by the individual hardness of the coatings and in this case the increasing amount of oxygen present in spraying [6].

4.0 Conclusion

HVOF thermal spraying method is a method to increase the resistivity of a material towards wear. It is successfully executed on the AISI 1040 medium carbon steel substrate. For this research, the aims are to determine the hardness of the coating when parameters are altered and also its resistance towards wear when there is changes in parameter, where in this case, the usage of different oxygen flowrate during HVOF spray.

The experimental results had revealed that samples that had been coated with a higher oxygen flowrate have the higher hardness. In terms of the wear resistance, it is proportion to the hardness, the coating's wear resistance increases as the hardness increase. To conclude, the resistance towards wear increases as the oxygen flowrate increases as well.

The following conclusions are drawn based on the results of comparison between the three different parameter changes in HVOF coating samples on the AISI 1040 medium carbon steel:

I. The surface morphology of the 3 samples shows no significant changes although the parameters are differed.

II. The HVOF sprayed AISI 1040 medium carbon steel showed lower hardness with lower oxygen value in compared to samples which is sprayed with higher oxygen content coatings.

III. The oxygen content in the HVOF coating influences the wear resistance of the material.

IV. The amount of oxygen content in the sample is directly proportional to the hardness and the wear resistance. The higher the amount of oxygen content (oxygen flowrate), the better the hardness, the better the resistance towards wear.

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