International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 12, Issue 7 (July 2016), PP.47-60

HV of Sprayed Cr_3C_2-Nicr Coating on Mild Steel and Brass for Linear Abraser Test

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Abstract: Surface modification such as surface coating is applicable to reduce the wear effects on components. Cermet, the combination of ceramics and metals is widely used in corrosive and aggressive environments where the wear risk is high. Chromium Carbide-Nickel Chrome (Cr_3C_2-NiCr) cermet can provide wear and corrosion resistance at high elevated temperature up to 1173 K. Having many advantages as a thermal spray, high velocity oxy-fuel (HVOF) is the most suitable technique for coating. HVOF can provide more enduring and more long-lasting surface coating. In this study, Cr_3C_2-NiCr is deposited onto mild steel and brass pins using HVOF thermal spraying. The wear rate of the coating is then measured in terms of weight loss after being scratched on 180 grit sandpaper using the linear abraser wear testing machine. The test was conducted according to its operating instructions. Based on the results, the wear rate increases with both increase of applied load and the test duration. However, the wear rate is more significant for the uncoated pins as they did not have any protective layer. The lifetime prediction of the coating is very important in the real industry to anticipate the time for re-coating to avoid extreme wear effects. As expected, the lifetime predictions for the coated pins are much longer than the uncoated pins for both wear tests. In Cr_3C_2-NiCr coating, NiCr alloy binder is a continuous matrix phase with Cr_3C_2 as hard reinforcement phase. This explains the higher weight percentage of Cr element compared to Ni element after the wear tests.

Keyword: Cermet, Cr_3C_2-NiCr,HVOF, Wear Testing, Coating.

I. INTRODUCTION

Wear can be defined simply as material loss or detached from the rubbing surfaces [1]. The surface of material has been the critical region as it can be subjected to corrosion, oxidation, radiation, abrasion or adhesion [2]. Erosion and corrosion are the major issues in oil exploration, particularly during exploration phase when the wear of materials such as drilling tools and pipes may occur [3]. Besides, the wear phenomenon in the automotive industry can be observed in the piston cylinder components where the piston slides the cylinder causes sliding wear on the inner part of the cylinder. Wear has been known as one of the major factors which shortens the lifetime and reduces the performance of components. Almost all machines lose their durability and reliability due to wear, including new advanced machines.

In order to prolong components' lifetime, modification of surface properties have to be done. Coatings can be applied to surfaces to improve surface characteristics and widely used in tribological applications either in reducing wear and/or to modify friction during sliding contact [4]. The main requirements of surface engineering are developing the surface coatings of high bond strength, high density, high hardness, low porosity, and refined microstructure [2].Gas detonation spray coating processes are well-known for providing premium quality coating with low porosity and high adhesion to protect the matrix from corrosion and wear [5]. Based on the literature [6], the automotive manufacturers have specified chromium plating to produce wear resistant coatings because of its appearance, wear and corrosion resistance. However the plating bath contains hexavalent chromium which has adverse health and environmental effects. Accordingly, thermal spray technology has been proposed as an alternative to hard chromium plating, showing in some applications promising results [7]. The modification of surface material will increase components' wear resistance, extend its lifetime and minimize the economic loss.

Cermet is a well-known class of materials that combine the positive properties of two groups of compound; ceramic and metals, being composed by a mixture of ceramic particles in a metal-matrix [8]. *WC-Co* and *Cr_3C_2-NiCr*are the examples of cermet which are widely known for its excellent tribological properties.

According to past study [9], *WC-Co*provides excellent performance at ambient temperature and has a temperature limit up to 625K. In contrast, *Cr_3C_2-NiCr* is employed at high elevated temperature up to 1173K for its excellent oxidation resistance and reasonable wear resistance. Consequently, *Cr_3C_2-NiCr*coating is widely used in engineering and aeronautic applications due to its good tribological properties in severe working conditions (high temperature and aggressive environments) and good oxidation and corrosion resistance [7]. Moreover,*Cr_3C_2-NiCr*is used in the production of hard coatings which are resistant against high temperature wear applications that may reach a maximum operating temperature of 1173K, offering superior oxidation and

corrosion resistance where Cr_3C_2 phase offers wear resistance while *NiCr* matrix provides corrosion resistance [3].

However, it is demonstrated that *WC-Co* coating showed higher wear resistance at ambient temperature and humidity compared to Cr_3C_2-*NiCr*because of its hardness, uniform and dense microstructure [10]. The oxide layer was identified in which it prevents the metal to metal contact, thus reduce the wear effect. Though it has higher hardness and wear resistance, *WC-Co* coatings are limited to temperatures below 723-803K. This is the main shortcoming of *WC-Co*as agreed by many researchers. Meanwhile in the industry, the selection of 75:25 of Cr_3C_2:*NiCr* as coating material was based on its use in the industry and its commercial availability [4].

The high velocity oxy-fuel (HVOF) thermal spray coating is a deposition technique by which the coating materials, in powder form, is fed into the combustion chamber of a gun where a fuel such as hydrogen, ethylene or kerosene is burned with oxygen, the heated and softened powders are expelled as a spray with the supersonic gases [6]. This technique is commonly applied to coat metal substrates. HVOF thermal spraying process has shown to be one of the best methods for depositing conventionalCr_3C_2-*NiCr* feedstock powders, because the hypersonic velocity of the flame shortens the time of interaction between the powder and the flame [6]. Also, the coating could be an alternative for the replacement of hazardous hard chromium plating technology [11].

Furthermore, it is reported that [4] the HVOF process has been shown to produce coatings with better density, coating cohesive strength and bond strength than many thermal spray processes. Consequently, HVOF process is suitable for coating purposes because it possesses high deposition efficiency compared to other thermal spray processes; the diffusion rate of the substrate elements to coating is smaller and the cost is lower than the laser technique [12]. Also, HVOF technique is the most promising methods among the available thermal spray processes which is capable of producing carbide cermet coatings with high density, strong adhesion, high cohesive strength and strongly limited reactions due to its moderate process temperatures and high gas velocities [13].

Abrasive wear testing is used to test the abrasive resistance of solid materials such as metals, composites, ceramics and coatings. In the journal,[14] abrasive wear is one of the many different modes of wear that accounts for more than 50% of all the wear problems and has been recognized as the most severe and the most commonly encountered by industry. This type of wear occurs when hard particles interact with a material surface, removing debris from it by mechanical action [15]. It is described that abrasion deteriorates the performance of coatings even though the coating is not fully abraded [16]. Additionally, it has been revealed that micro-scale abrasion is a relatively recent technique that is gaining wide acceptance for the wear testing of coatings and surface engineered materials [17].

II. METHODOLOGY

2.1Sample Preparation / Surface Coating

1. The surface of the substrates; mild steel and brass pins are sandblasted using Aluminium Oxide (Al_2O_3) at a pressure of 40 psi for surface cleaning and roughening.
2. Cr_3C_2-NiCrpowder is heated in the industrial oven up to 70°C to remove any trapped vapour to ensure that the powder is absolutely dry. Then, the powder is let to cool down for five minutes before being filled in the powder feeder.
3. The Cr_3C_2-NiCrpowder is deposited onto the surface of substrate using HVOF thermal spray coating with approximate thickness of 100 μm.
4. Then, both coated and uncoated pin samples are polished using a grinder-polisher starting with the coarsest sandpaper which is 180 grit and continued with 320, 600 and 800 grit sandpaper.
5. Each pin samples are then weighed using a precision balance and the weights are recorded precisely up to four decimal points.

2.2 Wear Testing

1. The Taber® Linear Abraser instrument is turned on by switching on the power.
2. Using the lock mechanism, the collets assembly is locked in the ‘up’ position.
3. The stroke length is set to be 25.4 mm.
4. Then, the mode is switched to ’run’.
5. The counter is set to the desired number of cycles and speed of the cycles per minute using the numerical keypad, while the weights are added manually. The table below shows the experimental setup for both Test 1 and Test 2.

Table 1: Variables for Test 1 and Test 2

	TEST 1 (varying applying load)	**TEST 2** (varying test duration)
Stroke Length	25.4 mm	25.4 mm
Speed	30 cycles per min	30 cycles per min
Weights (Applied loads)	350 g 600 g 850 g	600 g
Cycle Times (Test duration)	400 seconds	100 seconds 200 seconds 400 seconds

6. A strip of 180 grit sand paper is attached on the flat table, with the samples secured within the abrasion path. The laser guide can be used for this purpose.
7. The samples are properly set in the collet appropriately.
8. The lock mechanism is released and the collet assembly is gently lowered until the pin sample touched the sandpaper.
9. The abrasion process is started by pressing the 'start' button
10. Periodically, any loose abrasive particle or worn material is removed from the surface of sandpaper by light brushing.
11. When the test is complete, the lock mechanism is used to lock again the collet assembly in the 'up' position.
12. The pin sample is removed from the collet and weighed using precision balance. The measured weights are recorded to calculate the weight loss.

2.3 Microstructure Analysis

1. The microstructure of the pin samples are analyzed using the Scanning Electron Microscopy (SEM) integrated with the Energy Dispersive X-ray Spectroscopy (EDS). Table 2 below shows the summary of microstructure analysis using SEM-EDS.
2. SEM is an optical microscope equipped with image analyzer software. The results, in form of images, graphs and tables are then recorded for further discussion in Chapter 4.

Table 2: Summary of microstructure analysis

	Description	Magnification
Sample 1	Before Test	20x, 500x, 1000x, 1500x and 3000x
Sample 2	After Test 1	
Sample 3	After Test 2	

III. RESULTS AND DISCUSSION

3.1 The Wear Rate of Cr_3C_2-NiCr Coating

The wear rate of *Cr_3C_2-NiCr* coating is measured based on the calculated weight loss of the coated pin according to different applied load and test duration. As mentioned in the experimental methodology, each coated and uncoated pin was weighed before and after conducting the wear test in order to obtain its initial and final weights. From these measurements, the weight loss is calculated both in terms of gram and percentage. Equations below are used for calculations of weight loss and percentage difference. Table 3 and Table 4 summarize the weight loss of each pin after the wear test.

Equation of weight loss in gram :

$$Weight\ loss\ (g) = Initial\ weight\ (g) - Final\ weight\ (g) \quad (1)$$

Equation of weight loss in percentage :

$$Weight\ loss\ (\%) = \frac{Initial\ weight\ (g) - Final\ weight\ (g)}{Initial\ weight\ (g)} \times 100$$

(2)

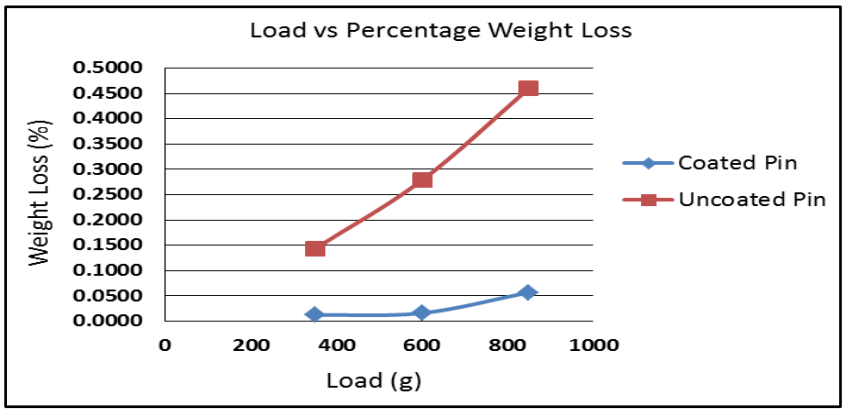
Equation of percentage difference of weight loss :

$$Percentage\ Difference\ (\%) = \frac{|\,Weight\ loss\ (uncoated) - Weight\ loss\ (coated)|}{Average\ of\ both\ weight\ loss\ (uncoated\ and\ coated)} \times 100$$

(3)

Table 3: Summary of weight loss for Test 1; different applied load

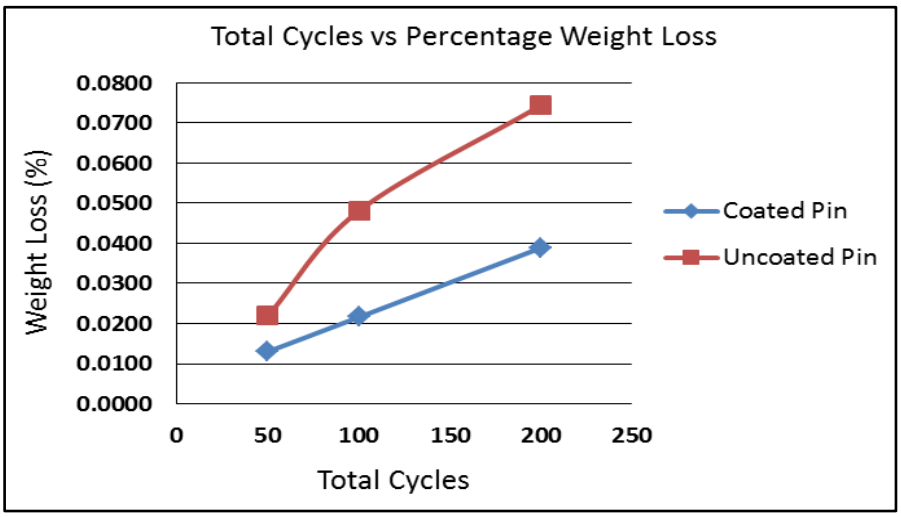
Coated Samples					
Sample	Load (g)	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Weight Loss (%)
Pin 1	350	2.4217	2.4214	0.0003	0.0124
Pin 2	600	2.4640	2.4636	0.0004	0.0162
Pin 3	850	2.4549	2.4535	0.0014	0.0570
Uncoated Samples					
Sample	Load (g)	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Weight Loss (%)
Pin 1	350	2.4463	2.4428	0.0035	0.1431
Pin 2	600	2.4428	2.4360	0.0068	0.2784
Pin 3	850	2.4360	2.4248	0.0112	0.4598



Graph 1: Comparison of weight loss based ondifferent applied loads

Table 4: Summary of weight loss for Test 2; different test duration

Coated Samples					
Sample	Total Cycles	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Weight Loss (%)
Pin 1	50	2.3124	2.3121	0.0003	0.0130
Pin 2	100	2.3116	2.3111	0.0005	0.0216
Pin 3	200	2.3154	2.3145	0.0009	0.0389
Uncoated Samples					
Sample	Total Cycles	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Weight Loss (%)
Pin 1	50	2.2858	2.2853	0.0005	0.0219
Pin 2	100	2.2853	2.2842	0.0011	0.0481
Pin 3	200	2.2842	2.2845	0.0017	0.0744



Graph 2: Comparison of weight loss based on different test duration

Graph 1 and Graph 2 illustrate the results of wear rate of both coated and uncoated pin samples in terms of percentage weight loss. The graphs are tabulated with independent variables; applied loads and test duration versus dependent variable; weight loss in percentage.

In Test 1, the highest and lowest value of weight loss for the coated pin is 0.0570% and 0.0124% respectively. Meanwhile, the highest and lowest value of weight loss for the uncoated pin is 0.4598% and 0.1431% respectively. These values are corresponding to 850 g and 350 g of applied loads. Using the Equation 3, the average percentage difference of both coated and uncoated pins between the highest and lowest weight loss is approximately 160%. It shows a very significant difference of weight loss between coated and uncoated pin.

In Test 2, the highest and lowest value of weight loss for the coated pin is 0.0389% and 0.0130% respectively. Meanwhile, the highest and lowest value of weight loss for the uncoated pin is 0.0744% and 0.0219% respectively. These values are corresponding to 400 s and 100 s of test duration. Using the Equation 3, the average percentage difference of both coated and uncoated pins between the highest and lowest weight loss is approximately 200%. It shows a very significant difference of weight loss between coated and uncoated pin, even higher than Test 1 which is 160%.

The calculated weight loss for the uncoated pins are relatively higher that the coated pins for both Test 1 and Test 2. The uncoated pins are more affected by wear as there is no protective layer. By increasing the weight of applied load and extending the test duration during the wear test, the wear rate will increase but will be more significant for the uncoated pins. Graph 1 and Graph 2 clearly illustrate that coated pins are more resistant to wear compared to the uncoated pins in both tests. Hence, it is proven that *Cr_3C_2-NiCr* cermet coating has excellent performance on wear resistant, giving a great impact on the surface.

3.2 The Lifetime of Cr_3C_2-NiCr Coating

The lifetime of *Cr_3C_2-NiCr* coating is calculated and predicted based on the weight loss of coated pins. Referring to Test 1, 0.0003 g of coated powder is loss when 350 g of load is applied during the test. The initial weight of the coating is 0.0134 g. Therefore, the time taken for the coating to wear completely can be predicted as shown in the calculation below. If the wear testing is conducted continuously for 5 hours, the entire 0.0134 g *Cr_3C_2-NiCr* coating on the pin will be scratched out.

Predicted time for 0.0134 gof coated powder to wear completely:

$$= \frac{0.0134\ g\ of\ coated\ powder}{Weight\ loss\ of\ coated\ powder\ (g)} \times Time\ (s)$$

$$= \frac{0.0134\ g}{0.0003\ g} \times 400\ (s)$$

$$= 1.8 \times 10^4\ s$$

$$\approx 5\ hours$$

Table 5: Predicted time for the coating in Test 1to wear completely

	Weight Loss	Duration
Experimental Results	0.0003 g	400 seconds
Lifetime Prediction	0.0134 g	5 hours

If 200 g of Cr_3C_2-*NiCr* powder is deposited on the pin, time taken for the coating to wear completely can be predicted. Based on the calculations, 200 g of coated powder will totally wear approximately after 8.5 years under 350 g applied load, while the time taken for 200 g of uncoated pin to wear entirely is approximately 0.7 years. Table 6 shows the life prediction for coated and uncoated pin at different applied loads.

Predicted time for 200 g of coated powder to wear completely under 350 g load:

$$= \frac{200\ g\ of\ coated\ powder}{Weight\ loss\ of\ coated\ powder\ (g)} \times Test\ duration\ (s)$$
$$= \frac{200\ g}{0.0003\ g} \times 400\ (s)$$
$$= 2.67\ \times 10^8\ s$$
$$\approx 8.5\ years$$

Predicted time for 200 g of coated powder to wear completely under 850 g load:

$$= \frac{200\ g}{0.0014\ g} \times 400\ (s)$$
$$= 5.71\ \times 10^7\ s$$
$$\approx 2\ years$$

Predicted time for 200 g of uncoated pin to wear under 350 g load:

$$= \frac{200\ g\ of\ uncoated\ pin}{Weight\ loss\ of\ uncoated\ pin\ (g)} \times Test\ duration\ (s)$$
$$= \frac{200\ g}{0.0035\ g} \times 400\ (s)$$
$$= 2.29\ \times 10^7\ s$$
$$\approx 0.7\ years$$

Predicted time for 200 g of uncoated pin to wear under 850 g load:

$$= \frac{200\ g}{0.0112\ g} \times 400\ (s)$$
$$= 7.14\ \times 10^6\ s$$
$$\approx 0.2\ years$$

Table 6: Lifetime prediction of coated and uncoated pins at different applied loads

		Experimental Results		Lifetime Prediction	
Sample	Load (g)	Weight Loss (g)	Duration (s)	Weight Loss (g)	Duration (year)
Coated	350	0.0003	400	200	8.5
Uncoated	350	0.0035	400	200	0.7
Coated	850	0.0014	400	200	2.0
Uncoated	850	0.0112	400	200	0.2

Moreover, it is important to distinguish the difference of weight loss between the *Cr_3C_2-NiCr* coated and uncoated pins to compare the lifetime. Again, 200 g will be set as the assumed weight loss in order to predict the lifetime. Referring to Test 2, the weight loss during 100 s test duration is 0.0003 g and 0.0005 g for coated and uncoated pins respectively.

Predicted lifetime for coated pin:

$$= \frac{200\ g\ of\ coated\ powder}{Weight\ loss\ of\ coated\ powder\ (g)} \times Test\ duration\ (s)$$
$$= \frac{200\ g}{0.0003\ g} \times 100\ (s)$$
$$= 6.7\ \times 10^7\ s$$
$$\approx 2.1\ years$$

Predicted lifetime for uncoated pin:

$$= \frac{200\ g\ of\ uncoated\ pin}{Weight\ loss\ of\ uncoated\ pin\ (g)} \times Test\ duration\ (s)$$
$$= \frac{200\ g}{0.0005\ g} \times 100\ (s)$$
$$= 4\ \times 10^7\ s$$
$$\approx 1.3\ years$$

Table 7: Comparison of predicted lifetime of 200 g coated powder

		Weight Loss (g)	Duration
Coated pin	Experimental Results	0.0003	100 seconds
	Lifetime Prediction	200	2.1 years
Uncoated Pin	Experimental Results	0.0005	100 seconds
	Lifetime Prediction	200	1.3 years

Based on the past literatures, it is proven that the coated components are more enduring and long lasting compared to the uncoated ones, which is subsequent with the experimental results. The lifetime prediction of the coating is very pertinent in the real industry as the engineers will anticipate the time to re-coat the components to avoid extreme wear effects in order to maintain the efficiency.

3.3 Microstructure Analysis of Cr_3C_2-NiCr Coating

The microstructures of the HVOF-sprayed *Cr_3C_2-NiCr*coating are shown in Figure 1; black colour represents the Chromium element while the white colour represents Nickel element in the micrograph. It is reported that the pores are due to the un-melted and semi-melted particles in the *Cr_3C_2-NiCr*coatings as identified by their spherical morphology [18]. This is considered as a low porosity value due to high impact velocity of the coating particles, which causes high density and high cohesive strength [19]. From the micrograph, it can be seen that the coating is uniform, homogeneous and free from surface cracks and debris of chips.

Three spots are randomly chosen to identify the distributions of different elements of the coating. Figure 3 shows the Energy Dispersive X-ray Spectrocopy (EDS) profile for *Cr_3C_2-NiCr* coated sample, where *Cr_3C_2*and *NiCr* binder are the major phases identified. The factor that high volumes of carbides are well dispersed in the matrix might be responsible for the lower porosity found in this coating [3,7]. Chromium is present the most at spot 2 with 100% weight percentage compared to spot 1 and spot 3 with weight of 15.9% and 54.5% respectively.

The different concentration of Chromium (*Cr*), Nickel (*Ni*) and Oxygen (*O*) based on the cut out map is illustrated in Figure 4. For each element, darker colour indicates high elements' concentration shown by the circles. All three elements are then merged together and *Cr* is the most recognizable element because it has the largest area of distribution and the highest weight percentage which is 55.2%, followed by 28.1% *Ni* and 16.7% *O*. Based on the EDS profile of cut out map in Figure 5, *Cr* shows the highest peak meaning the highest element concentration.

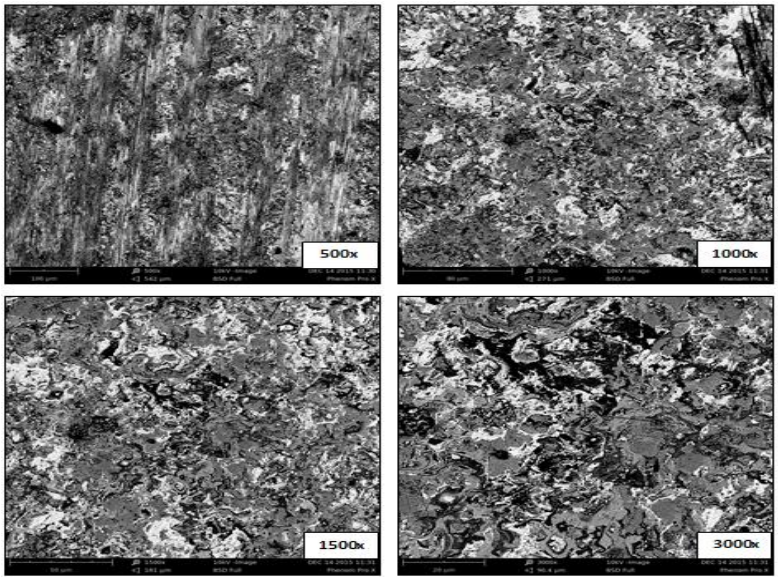


Figure 1: Cr_3C_2-NiCr coating before wear test at different magnifications

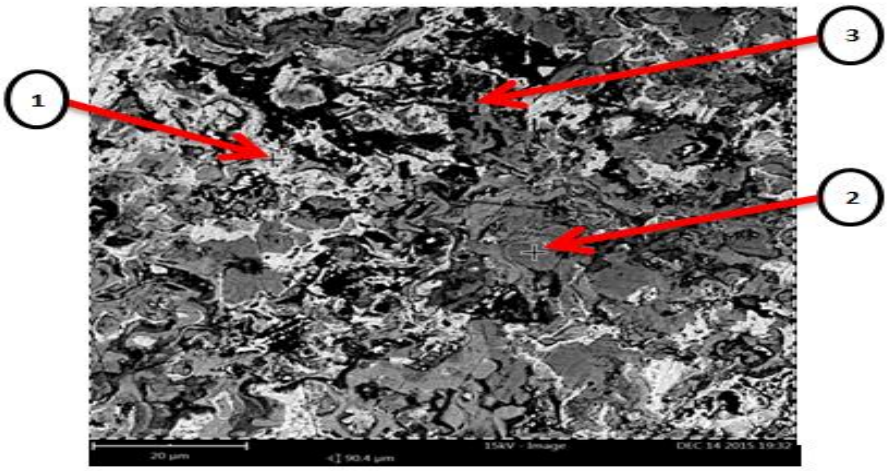
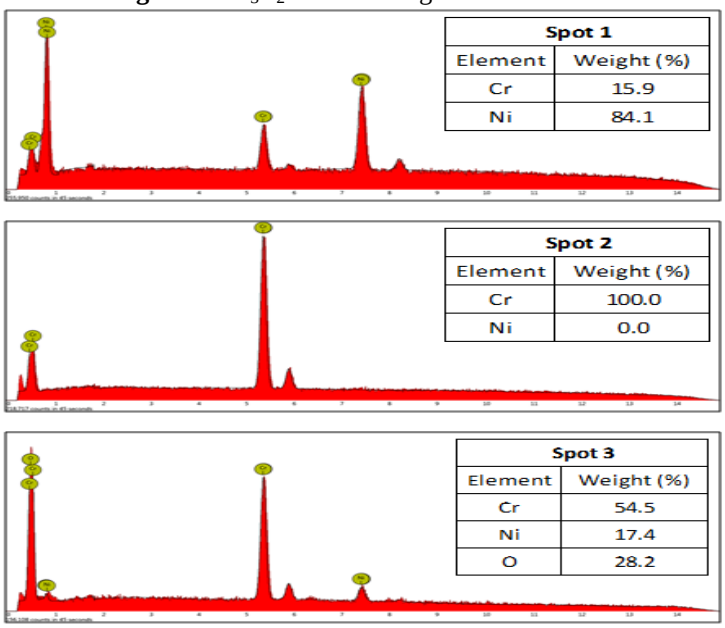


Figure 2: Cr_3C_2-NiCr coating before wear test



Spot 1	
Element	Weight (%)
Cr	15.9
Ni	84.1

Spot 2	
Element	Weight (%)
Cr	100.0
Ni	0.0

Spot 3	
Element	Weight (%)
Cr	54.5
Ni	17.4
O	28.2

Figure 3: EDS profile of Cr_3C_2-NiCr coatingbeforewear test

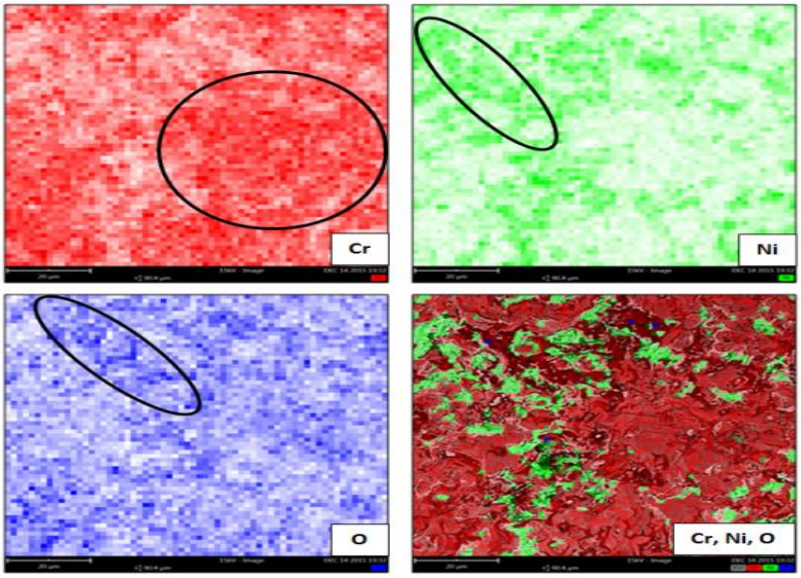


Figure 4: Cut out map SEM analysis of Cr_3C_2-NiCrcoating before wear test

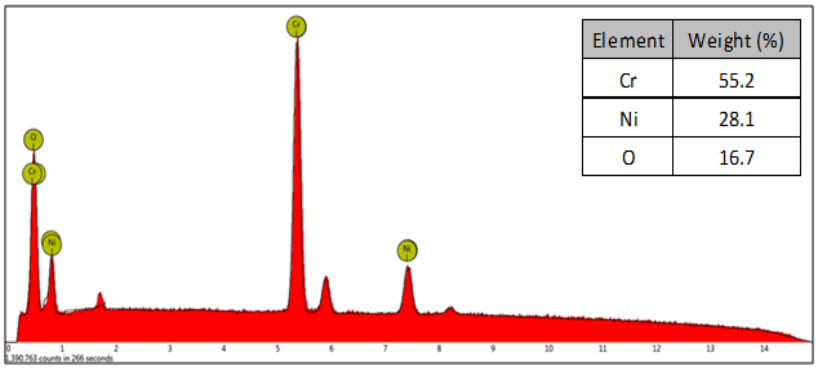


Figure 5: Cut out map EDS profile of Cr_3C_2-NiCrcoating before wear test

In this study, the regions of wear from the coated samples at different applied loads and different test duration of wear testing are investigated using SEM-EDS. Figure 6 and Figure 7 illustrate the surface of coating after conducting wear test; Test 1 and Test 2 at different magnifications. It can be observed that the wear rate is uniform, no surface cracks and debris of chips on the pin samples. Increasing applied load and extending test duration resulted in slight abrasion and wear tracks, in which however appear to be smooth and uniform as they looked before testing.

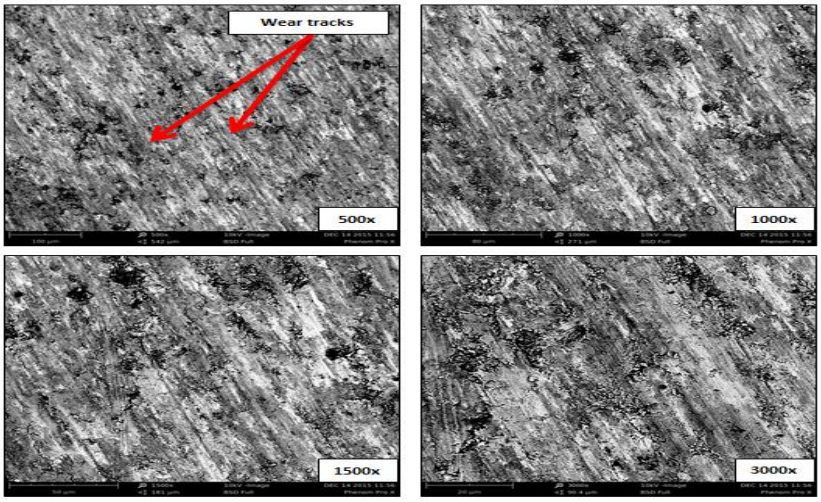


Figure 6: Cr_3C_2-NiCr coating after Test 1at different magnifications

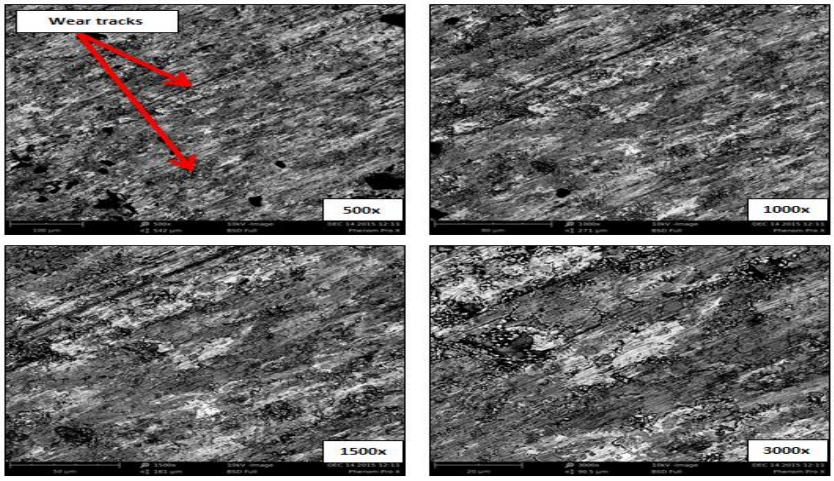


Figure 7: Cr_3C_2-NiCr coating after Test 2 at different magnifications

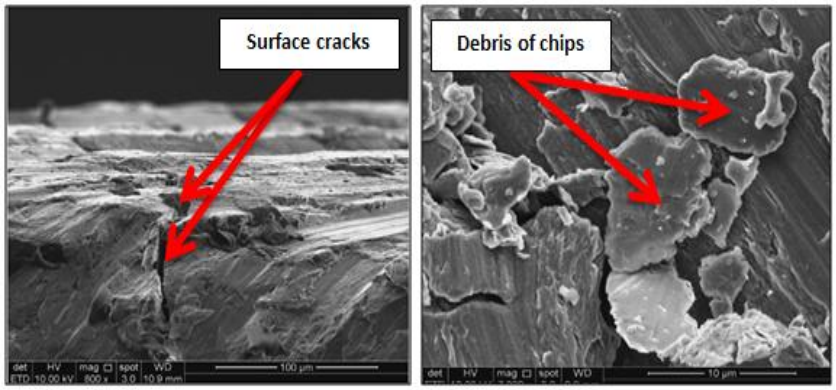


Figure 8: Micrograph of surface cracks and debris of chips [3]

Three spots are randomly chosen to identify the distributions of different elements of the coating namely *Cr* and *Ni*. Figure 9 shows the *Cr_3C_2-NiCr* coating after being tested by different applied load (Test 1). Meanwhile Figure 10 shows the EDS profile for *Cr_3C_2-NiCr* coated sample after the wear test. The weight percentages of *Cr* and *Ni* in spot 1 and spot 2 are 29.0% and 71.0%, 22.9% and 77.1% respectively. Both spots have higher concentration of *Ni*. However, 59.1% of *Cr* and 40.9% of *Ni* are observed in spot 3.

The different concentration of *Cr*, *Ni* and *O* after conducting Test 1 based on the cut out map is illustrated in Figure 11. For each element, darker colour indicates high elements' concentration. All three elements are then merged together and *Ni* has the highest weight percentage which is 42.4%, followed by *Cr* and *O*. However, the weight percentage difference between *Cr* and *Ni* is only 0.7% which is insignificant. The oxide layer is formed by the rubbing actions between the coated powder and sandpaper during the wear test. *Cr* reacts with *O* to form Chromium Oxide (Cr_3O_2) thus forming an oxide layer. The presence of oxides on the surface is good for wear resistance, which increase the strength of coated powder on the pin surface.

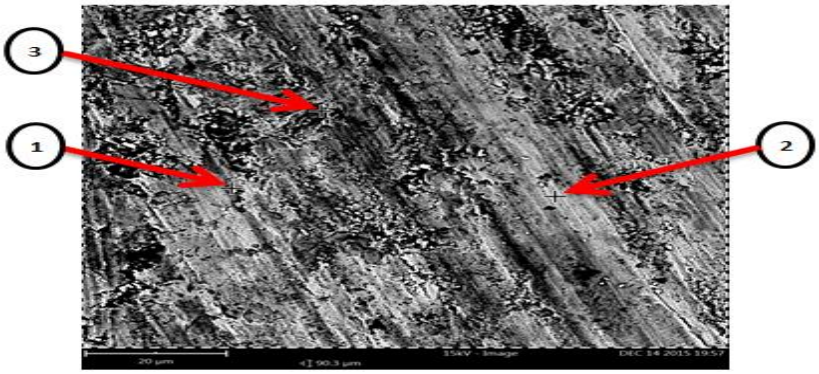


Figure 9: Cr_3C_2-NiCr coating after Test 1;different applied load

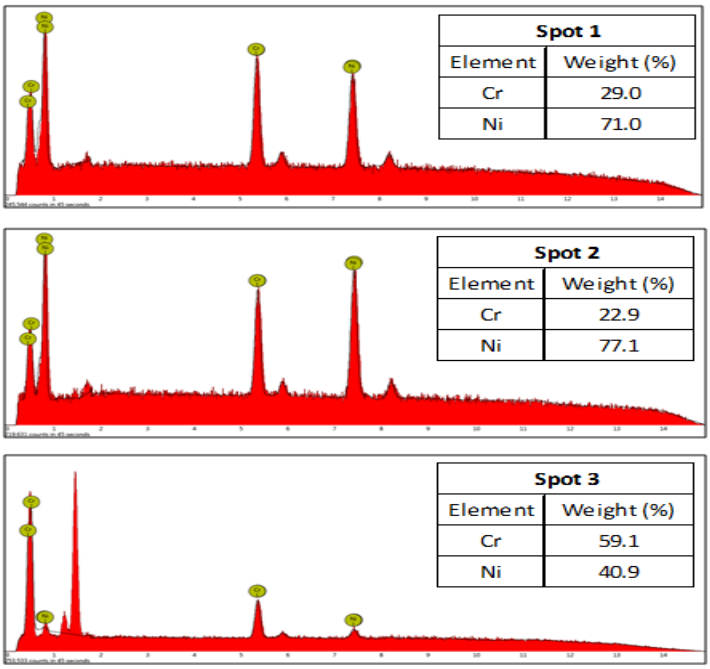


Figure 10: EDS profileof Cr_3C_2-NiCr coating after Test 1;different applied load

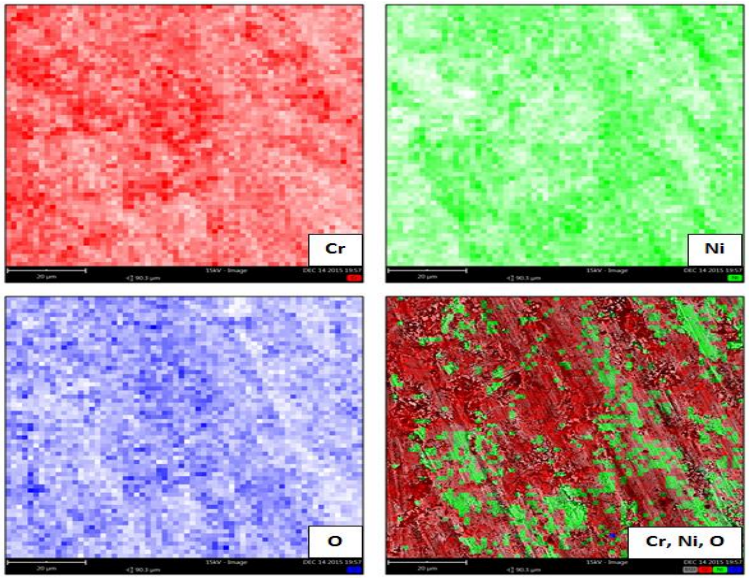


Figure 11: Cut out map SEM analysis of Cr_3C_2-NiCrcoating after Test 1; different applied load

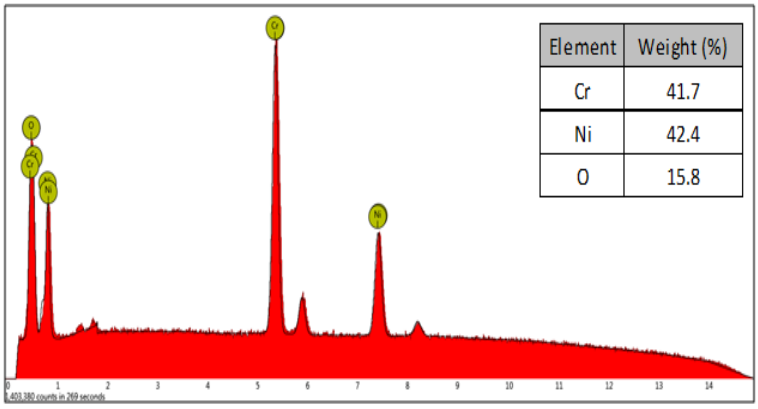


Figure 12: Cut out map EDS profileof Cr_3C_2-NiCrcoating after Test 1; different applied load

Three spots are randomly chosen, similar to Test 1 in order to identify the distributions of different elements of the coating namely *Cr* and *Ni*. Figure 13 shows the *Cr_3C_2-NiCr* coating after being tested by different test duration (Test 2). Meanwhile Figure 14 shows the EDS profile for *Cr_3C_2-NiCr* coated sample after the wear test. The weight percentage of *Cr* and *Ni* in spot 1 is 33.8% and 66.2% respectively, indicates higher concentration of *Ni*. Nevertheless, spot 2 and spot 3 have higher concentration of *Cr* compared to *Ni*, which is 96.9% and 95.5% respectively. The difference of concentration between *Cr* and *Ni* in spot 2 and 3 are very significant, which can be concluded that *Cr* is more wear resistant than *Ni*.

The different concentration of *Cr*, *Ni* and *O* after conducting Test 2 based on the cut out map is illustrated in Figure 15. For each element, darker colour indicates high elements' concentration. All three elements are then merged together and *Cr* has the highest weight percentage which is 53.8% and followed by 30.9% *Ni* and 15.3% *O*. *O* is present in form of oxide layer similar as the results in Test 1. Besides, the weight percentage of *O* in both Test 1 and Test 2 has no much difference, 15.8% and 15.3% respectively.

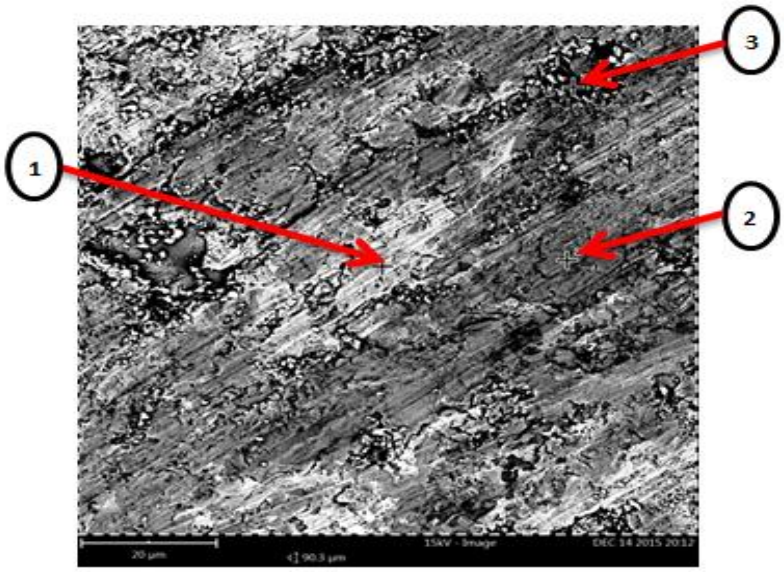
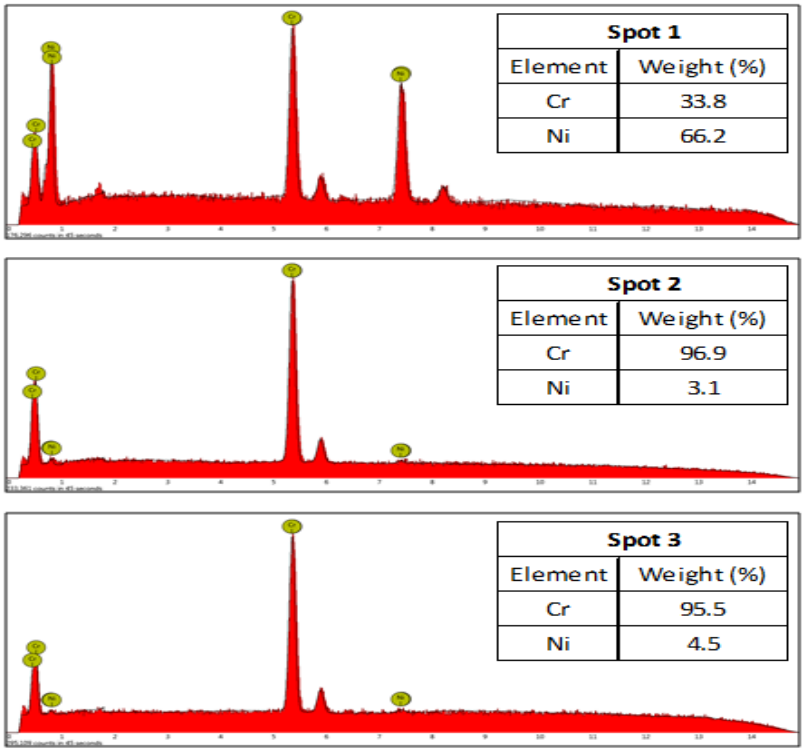


Figure 13: Cr_3C_2-NiCr coating after Test 2;different test duration



Spot 1	
Element	Weight (%)
Cr	33.8
Ni	66.2

Spot 2	
Element	Weight (%)
Cr	96.9
Ni	3.1

Spot 3	
Element	Weight (%)
Cr	95.5
Ni	4.5

Figure 14: EDS profileof Cr_3C_2-NiCr coating after Test 2;different test duration

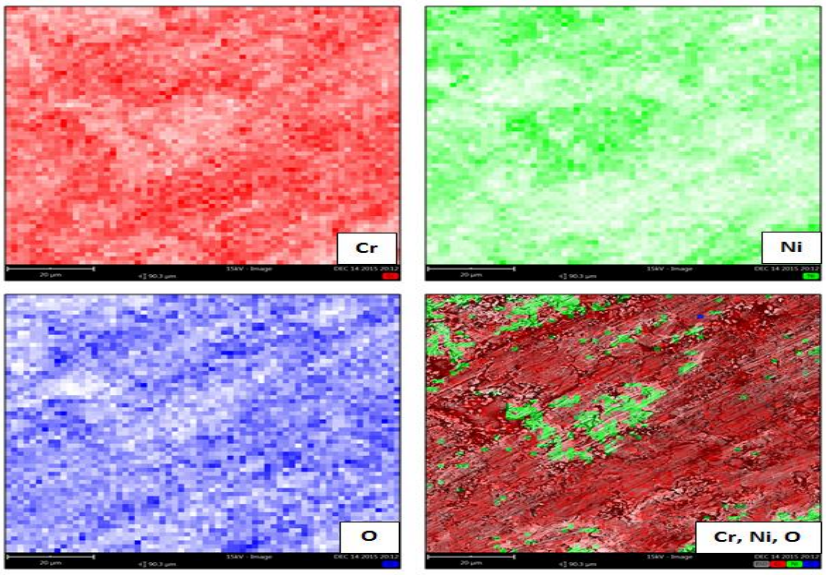


Figure 15: Cut out map SEM analysis of Cr_3C_2-NiCr coating after

Test 2; different test duration

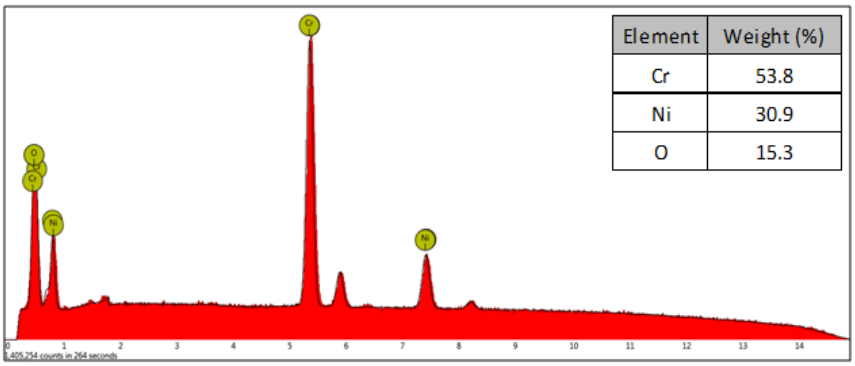


Figure 16: Cut out map EDS profileof Cr_3C_2-NiCr coating after Test 2; different test duration

IV. CONCLUSION AND RECOMMENDATIONS

- Increasing the applied load and extending the test duration during the wear test resulted in increasing wear rate but more significant for the uncoated pins.
- Coated powder pin has longer lifetime prediction compare to the uncoated pin, for both wear tests.
- The microstructures of *Cr_3C_2-NiCr* coated pins after the wear tests appeared to have uniform wear rate, no surface cracks and debris of chips.
- In *Cr_3C_2-NiCr* coating, *NiCr* alloy binder is a continuous matrix phase with *Cr_3C_2* as hard reinforcement phase. This explains the higher weight percentage of *Cr* element compared to *Ni* element after the wear tests.
- The presence of oxides on the surface coating is good for wear resistance, which increase the strength of coated powder.
- It is recommended to search for a stronger coating powder than *Cr_3C_2-NiCr* cermet, making an improvement in the matrix alloy hardness and bonding strength between carbides and the matrix.
- It is also recommended to conduct the wear test using the pin-on-disc machine according to ASTM G-99 for better outcomes.

ACKNOWLEDGEMENT

Alhamdulillah, all praises to Allah for the strength given and blessings in completing this thesis. I would like to give special thanks and appreciation to my supervisor, Associate Professor Dr. Subhash Kamal for his supervision and continuous support. He has been very helpful and supportive, giving constructive comments and suggestions which lead this project to success.Not forgetting Mr. David from MetaTech Sdn. Bhd. company for assisting me in sample preparation.

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