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Lubricated Conditions Imposed on Coating Multi-layer on Wear Resistance Under Cr_2O_3 Effect

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Lubricated pin-on-disk sliding wear tests were performed on applied to Al-0.1Mg-0.35Ni-Si Alloy by using the spray coating method has been investigated. Different loads were 5, 10, and 15 N at a sliding velocity, 1.32 m/s at room temperature and 60% relative humidity. The surfaces were analyzed by using X-ray diffraction the residual (XRD), energy dispersive (EDS), scanning of (SEM) and (AFM), respectively. The results have showed that the thickness of Cr_2O_3 coating was significantly related under the identical cold spray condition. These methods have contributed much of the understanding of quality and properties of surfaces. The (Cr_2O_3) coating has great potential as a wear-resistant. The hardness increased from 102 ± 5 HV to 116.4 ± 2.5 HV at coating thickness 45 μm and friction coefficient reduced from 0.29 to 0.24; and the wear rate was about $2.11X10^{-13}$ $m^3N^{-1}m^{-1}$ while hardness was increased from 102 ± 5 HV to 108 ± 3.5 HV at coating thickness 15 μm. The friction reduced from 0.31 to 0.29 at same coating thickness alloys, and the wear rate was about $2.73X10^{-13}$ $m^3N^{-1}m^{-1}$. The tribological properties of Cr_2O_3 coating have exhibited low friction and beneficial to improve the adhesion which was clear on worn surfaces of Cr_2O_3 coating. Crack, powder flocculation and powder formation are caused by the wear mode of the surface. Brittle fracture was found; while, adhesion and oxidation are the main mechanism of wear during the test.

Keywords: *Cr_2O_3, Coatings, Friction, Wear.*

1. Introduction

To reduce emissions and improve fuel efficiency of natural resources in the automotive industry, by reducing friction in the engine and vehicle weight and transmission systems[1]. The researchers are agreed that the treatment of the surface and the general practice are used to extend the life of parts and structures, especially if the surface is the most popular deals in the engineering components[2]. Plasma deposition Cr_2O_3 and Ni/Cr, Al_2O_3, TiO_2, and Al_2O_3-TiO_2 coatings of wear-resistant coatings are widely used in the automotive industry; it has advantages that help in further realization of mass production technology[3].

Bakshi and Wang[4] have used the coatings containing Al 11.6 % Si was fabricated using cold spraying. Their results have shown the hardness is increased as the fraction of alloy increases. The friction of Al coating was reduced on Al-Si. While, Bao and Zhang[5] have utilized composite coatings of Al-Si reinforced with 2% volume. Nanodiamonds were synthesized by plasma spraying. The effect on microstructure, hardness and tribological performance nanodiamonds composite coatings were examined. Plasma spray coated nanodiamonds have excellent potential as wear resistant coatings in the automotive industry. Nanotechnology has the popularity among manufacturers due to results obtained by controlling the materials composition. (DLC) coatings are well-known solid lubricants which can provide low wear rate of sliding interface in dry conditions[6]. Wang et al.[7] have researched the tribological coating, and the compatibility between the piston skirt and of Al or cast iron bore counter surfaces. The results have shown that Al piston skirt coatings and composites Ni P BN coating internal resistance and friction durability without oil to 390 Al[8]. It is evident from these studies that although inconsistent results were obtained for similar types of DLC, the hydrogen concentration is important in the film forming property of coatings. Ceramic coatings were improved for tribological characteristics of increased temperature where notified through solid lubricant. The mixture was to obtain a homogeneous distribution by drying powder spray Cr_2O_3-CaF_2 in the lubricant composite coatings of plasma spraying[9,10]. Thermal spray processes were combined to ensure the microstructure, mechanical and tribological properties of nanoparticles have conflicting results.

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The goal of this work is to study the effect of coating thickness under lubricated sliding contact and to investigate tribological properties of Cr_2O_3 coating (chromium (III), oxide nanopowder, <100 nm) to reduce the adhesion of the surfaces. Really, the focused considerable attention on these materials for a wide range of Cr_2O_3 coatings, wear-resistant in different aerospace and automotive industries have Cr_2O_3-based ceramic coatings, which displays favorable tribological behavior of high anti-wear and easy lubrication oil. The effect of nanopowder has excellent potential as wear resistant coatings in the automotive industry. In an internal combustion engine, coatings and surface treatments are often used for one or more elements of pistons, piston rings and cylinder liners used by the system. However, it is a first study to show comparative assessment of nanoparticles. This research is divided as; 2 presents the experimental, followed by results that detailed in section 3. The conclusions are outlined in section 4.

2. Experimental Process

The surface modification using spray coating method (chromium (III), oxide nanopowder, <100 nm) to improve the tribological properties of Al-Si alloys, microscopic modes wear Cr_2O_3 coatings and wear transitions. Samples were prepared for the coating process, cylinder 30 mm in length and 10 mm in diameter, Ra = 0.25 ± 0.05 µm; carrier gas pressure was 1 bar (~ 3.0 GPa) compared with the initial gas pressure. The nozzle-substrate distance opposition to all spray runs was fixed at 15 mm. Coating thickness was (15, 30 and 45) ± 0.05 µm, a multi-layer coating and the same tolerances for easy comparison of thickness effect of layer to obtain the best properties. Different loads were 5, 10 and 15 N at a constant sliding speed, 1.32 m/s, disk of steel AISI 1045, Ra = 0.15 ± 0.05 µm, Hv = 312 ± 20 kg/mm^2, relative humidity ≈ 60 ± 2% and temperature = 28 ± 3 °C. The effect of wear was analyzed using. X-ray within 40 kV and 30 mA and scanning (SEM) and Atomic Force (AFM) (SPA 400, Japan) with scanning through a length line 5000 nm and a scanning rate of 1 Hz of the surface topography. The machine of wear tests were ASTM G-99 under lubricated. The mass loss after each test was estimated by measuring the weight before and after each test using an electronic weighing machine has an accuracy up to 0.0001 mg. The data of Lubricant are given in Table 1.

3. Results and Discussion

The results summarized and lead to investigation of effect of Cr_2O_3 coating multi-layer under lubrication and how wear process at different circumstances of thickness and microstructures. Metallographic analysis was carried out through topography, morphology and structural properties. Figures 1 shows the triple hybrids between particles. Some of the particles look flake and cohesion, there is difference between the surface morphology of anticorrosion coating of small particles, storage, while large corrosion particle produces in the form of slots that is attributed to increasing distance between the particles of the coating material, presence of porosity that increases the corrosion rate of alloys, where Al concentration increases dramatically, while Fe and O concentrations decrease. The matrix consists of fracture of particles of different sizes, microgrooves parallel sliding and mixtures mainly, Al, Si, Co, Cr. Due to available partial delamination tribolayer, groove was smoother than the original surface. Furthermore, SEM has showed the coating was smooth and filled the interstices between and formation of wear products is observed in worn surfaces. XRD was utilized to analyze the peaks that are consistent with SEM. The microstructure was observed using a high resolution and depth too. The residual voltage was measured via XRD data to obtain surface area of samples as shown in Figure 1. SEM and XRD of the composite coating at thickness 15 ± 0.05 µm (a), (b) SEM image of smooth coating surface and (c) wear particles.

Illustrate the friction coefficient and wear rate, respectively a thickness 15 ± 0.05 µm was tested with a sliding lubricant as shown in Figure 2(a) and compared to other thicknesses (b) and (c). At coating thickness 45 µm, the friction coefficient reduced from 0.29 to 0.24 as shown in (Figures 3 and 4); and the wear rate was about $2.11X10^{-13}$ m^3N-$^1m^{-1}$ while at coating thickness 15 µm, the friction reduced from 0.31 to 0.29 and the wear rate was about $2.73X10^{-13}$ $m^3N^{-1}m^{-1}$ at same coating thickness. The hardness increased from 102.5 HV to 116.4 ± 2.5 HV at coating thickness 45µm, while hardness was increased from 102.5 HV to 112.5 ± 3.5 HV at coating thickness 30 µm and from 102 ± 5 HV to 108 ± 3.5 HV at coating thickness 15µm respectively. The wear behavior has been correlated with the hardness. However, there is a decreasing of wear rate and an increasing of hardness when compared with samples by coating thickness. At coating thickness (15, 30 and 45) µm, an increasing in the matrix hardness is shown. This clearly indicates that, in most cases, the rate of wear increases simultaneously as applied load increases. This is due to applied load enhances friction on the surface of the material, which increases the rotor motion. The values of wear parameters indicate that the matrix gets powdered thereby damaging the fibers in specific areas of the sample[10]. The mechanism is accepted wear for the coating

Table 1. Lubricant data.

Lubricant type	Viscosity (mm^2/s) index, ASTM D 2270	Additives	Density (g/ml)	Flash point, ºC, ASTM D 92
Mobil 1	171	None	0.97	220

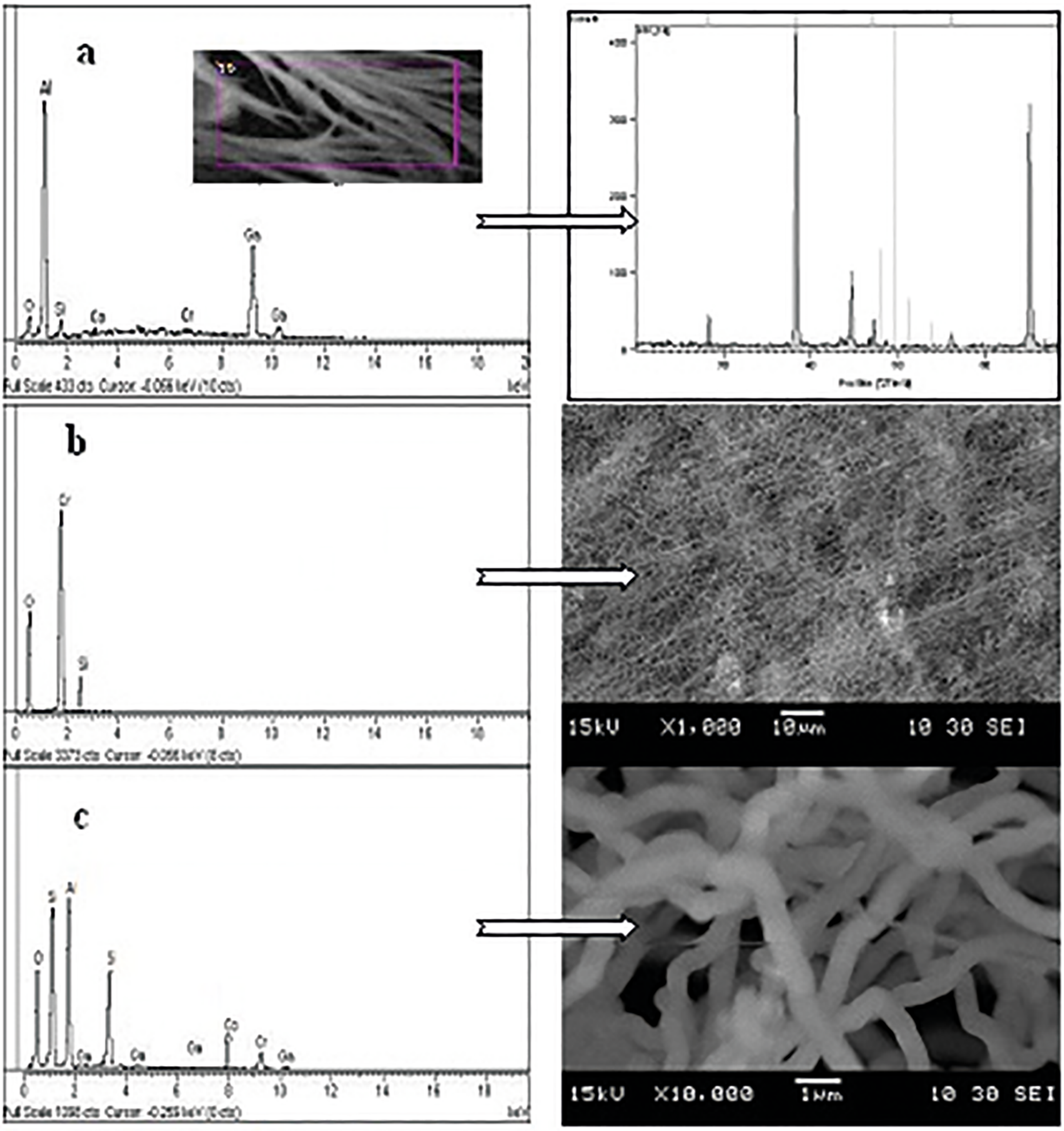


Figure 1. SEM and XRD of the composite coating at thickness 15 ± 0.05 µm (a), (b) SEM image of smooth coating surface and (c) wear particles. Corresponding SEM-EDS.

thickness, as known in terms of contact under conditions lubricant. In some cases, control debris transfers from the surface of sample on the surface of the disk due to difference of hardness and relationship is a little complicated. From the corresponding SEM-EDS spectrums showed in Figure 2. The shape of particles appear similar to each other and the particles distributed in the images show the wear resistance to the hardness of coating and the relationship between thickness and hardness, especially according to the three coatings' microstructures presented in Figure 2.

Figures 3 and 4 illustrate the wear rate and friction coefficient, respectively at thickness 45 ± 0.05 µm decreases with load 10 N compared with coating thicknesses 15 and 30 µm. The increasing of load leads to plastic deformation, where a real contact area increases and thus the temperature of the sliding surfaces increases, thereby reducing the soft parts of the shear forces. However, increasing the thickness of coating lead to increasing the cohesion and reducing wear. Obviously, values of wear are reduced with increasing thickness up to 45 µm, it can be increased due to growth of the relationship between the surface hardness and lubricant. The coefficient of friction was reduced over the surface area that is attributed to decreasing contact area. Microstructure and hardness of Cr_2O_3-coating were strongly associated with the thickness. Although these values have no significant difference, it can be due to the relationship

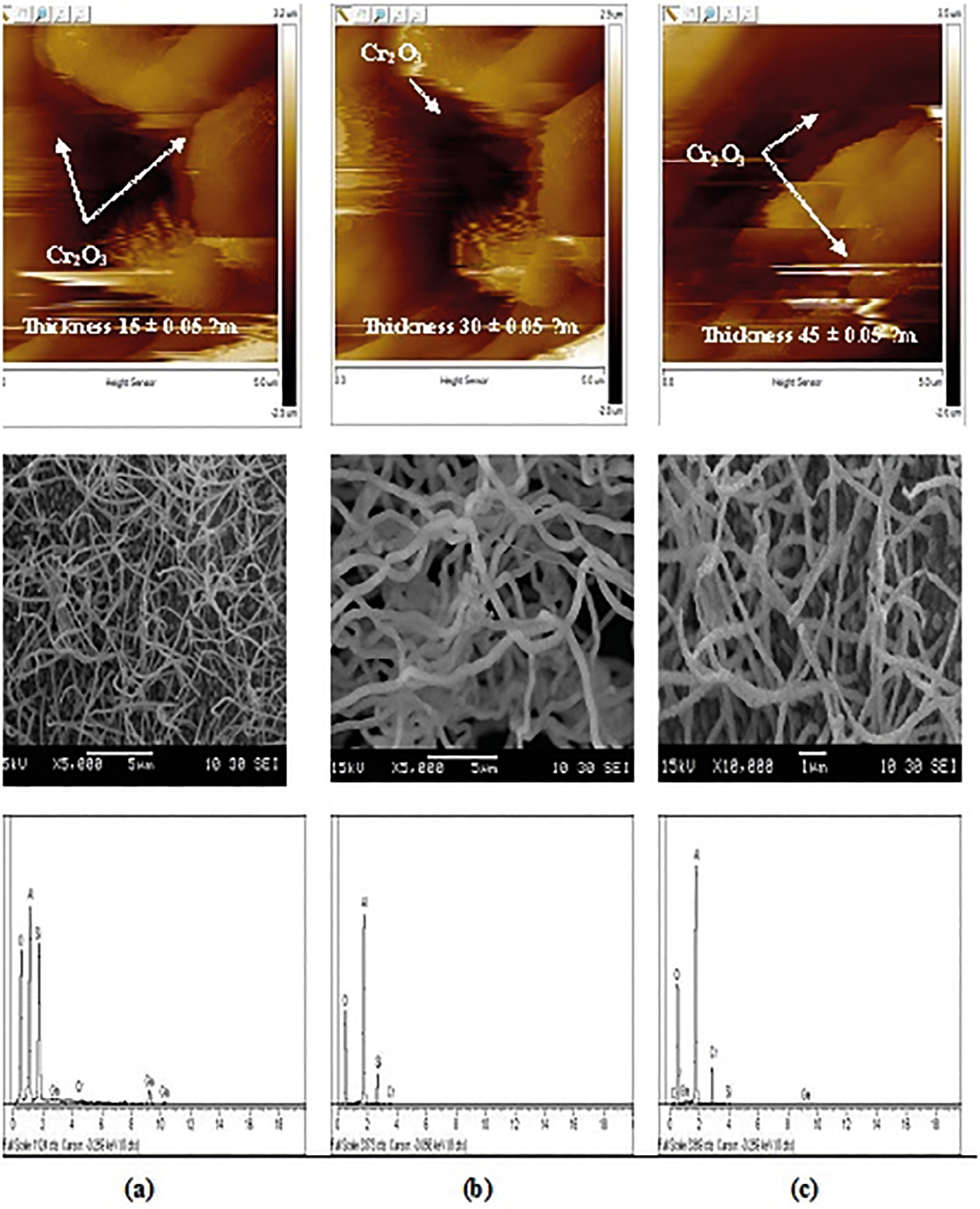


Figure 2. SEM of coating at thickness for (a) 15 ± 0.05 µm (b) 30 ± 0.05 µm and (c) 45 ± 0.05 µm after 60 min and 200 rpm

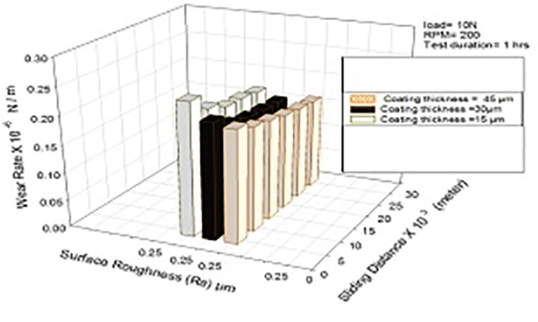


Figure 3. Wear rate with sliding distance.

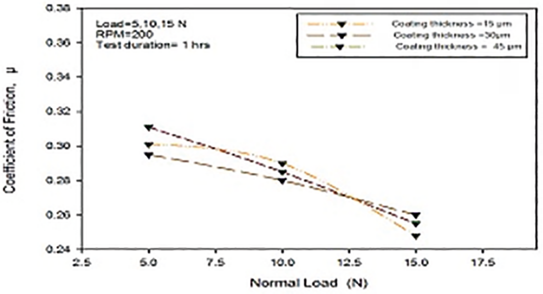
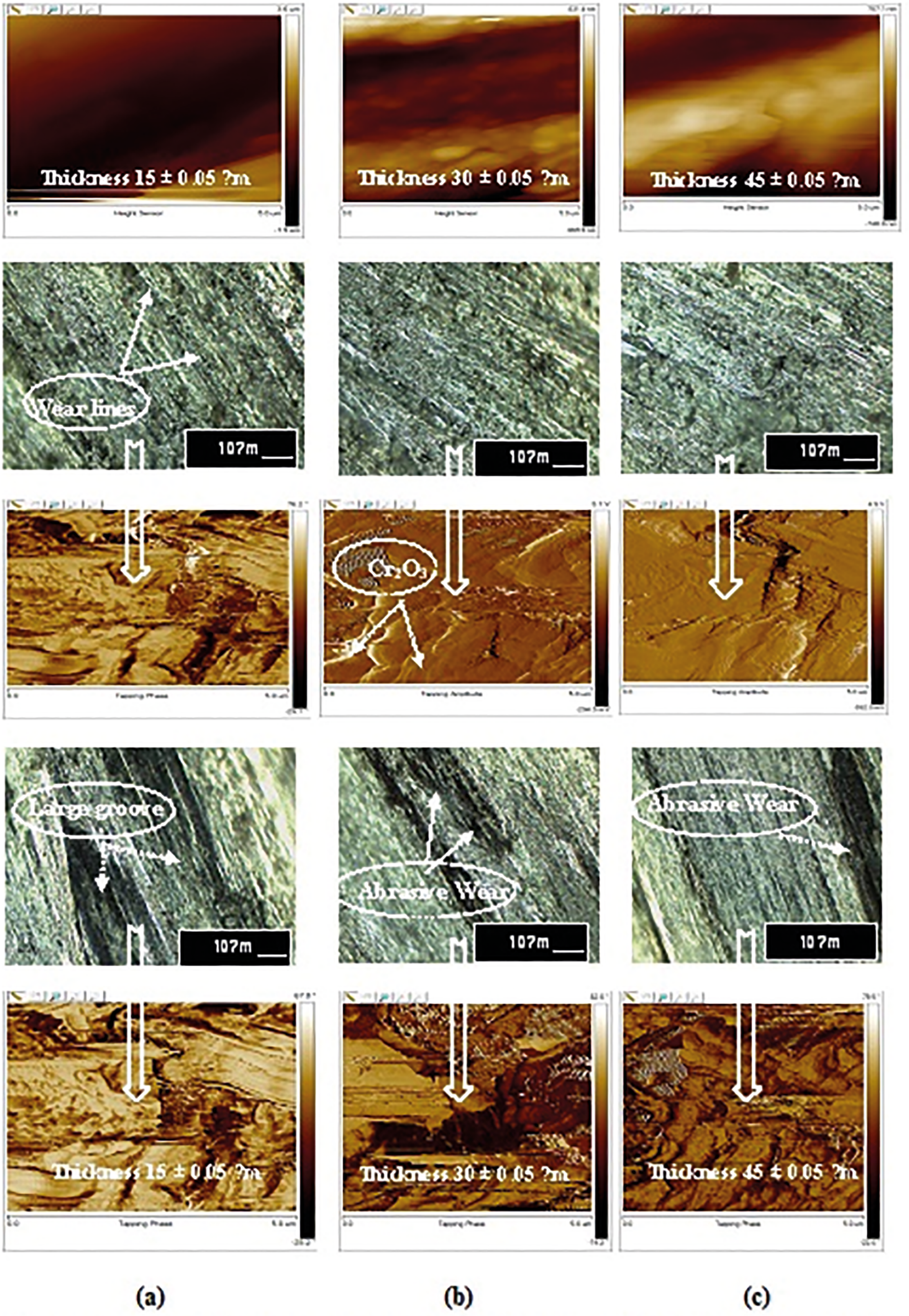


Figure 4. Friction coefficient with load.



(a) (b) (c)

Figure 5. SEM of surface wear under load 10 N & 200 rpm at thickness (a) 15 ± 0.05 μm (b) 30 ± 0.05 μm and (c) 45 ± 0.05 μm, corresponding AFM.

between the hardness of the coating material surface with lubrication, to reduce adhesion. However, these methods have contributed much of understanding of the quality and properties of surfaces.

Figure 5 presents the surface nature change and roughness of the samples. Thickness, 45 ± 0.05 µm has recommended best result. Surface studies show usually three types of mechanisms as adhesive, abrasive and oxidizing occurs in the Al-Si alloy. There was a big change on the sliding portion of the surface. Such problems, optical samples were used and micro-graphs of the surface profile curve for analysis. The particle coating shows a uniform distribution. Analysis of surfaces shows less the friction can be related of lubricants and thickness. Wear rate in surface is strongly dependent on the components of the layer and the coating thickness. Brittle fracture was found, adhesion and oxidation are to be the main mechanism of wear during the test[11].

A depth profile of each curve is displayed in Figure 6, which reflects the effect of the tribological properties at a thickness 45 ± 0.05 µm. For various areas of wear track

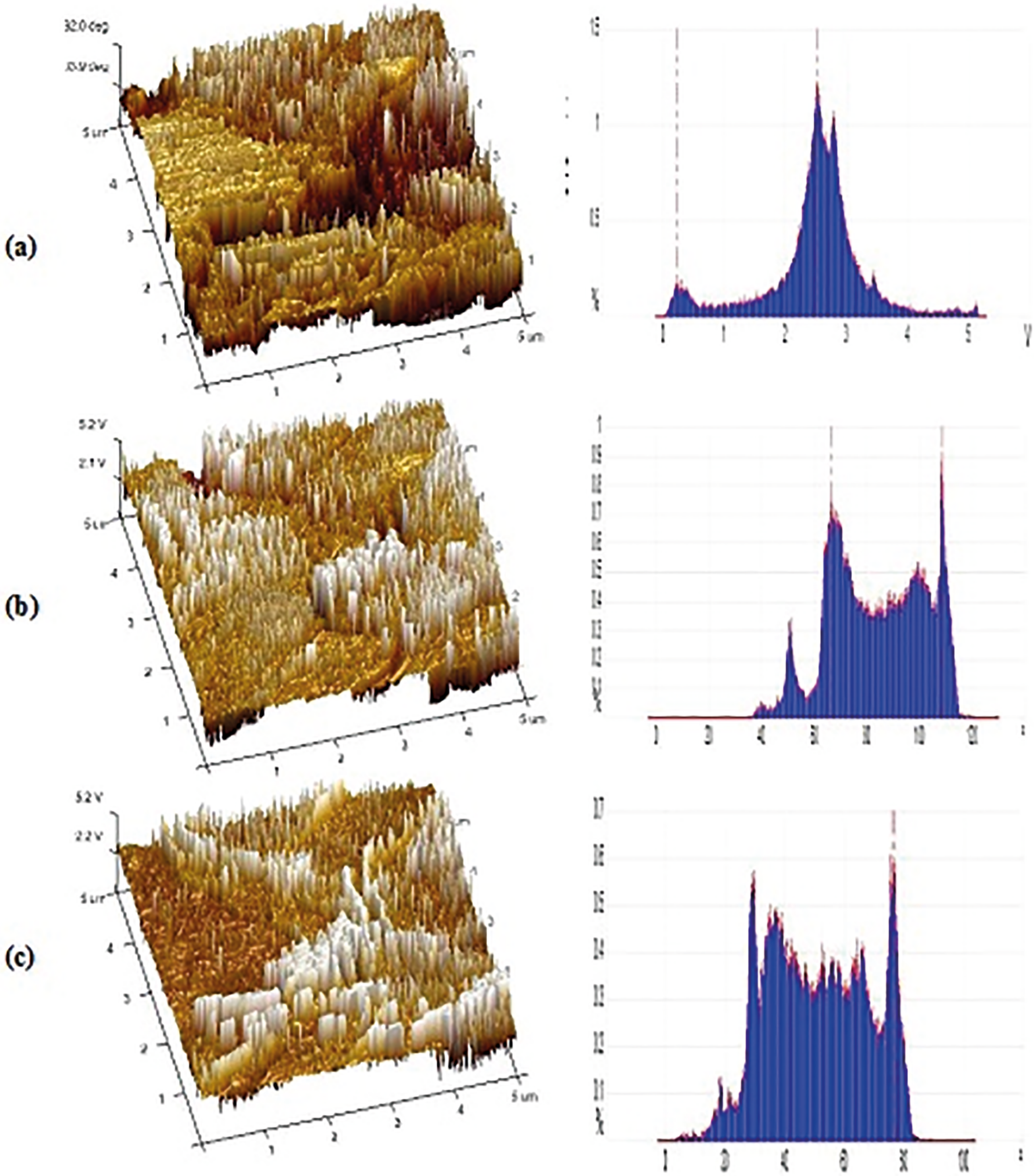


Figure 6. Average surface profiles, load 10 N and lubricated contact at 200 rpm after 60 min, at thickness (a) 15 ± 0.05 µm (b) 30 ± 0.05 µm and (c) 45 ± 0.05 µm.

after 60 min, load 10 N and lubricated contact at 200 rpm alloy, mean wear depth of thickness 45 ± 0.05 µm, compared to thickness 15 and 30 ± 0.05 µm were almost similar. However, as thickness of coating increases, the cohesion and hardness increase while wear decreases. *In-situ* tests have shown that the thickness of coating 45 ± 0.05 µm can give useful information that will be used to select the appropriate application of working conditions in order to optimize the performance and durability of the various pistons and blocks components in automotive engine which this multi-layer coating is applied[12].

The wear rate of chromiumoxide, nano powder, (Cr_2O_3) coating was monolithic and containing relatively low capacity of the particle increases gradually, but the wear increases more rapidly. This may be due to the fact that it is the combined effect of the real contact area and fissures. In addition, wear coefficient increases significantly with increasing porosity of (Cr_2O_3) coating. Sometimes the contributions of strengthening particles to increase wear resistance had been destroyed a high content of porosity. However, amount of porosity can be tolerated in the cast-reinforced composites without compromising its durability significantly[13].

Finally, Figure 7 presents the wear rate that is strongly depending on the components of the layer and coating thickness. The effect of lubricant on the tribolayer formed during sliding may reduce the friction. Brittle fracture was found, while adhesion and oxidation are the main mechanism of wear.

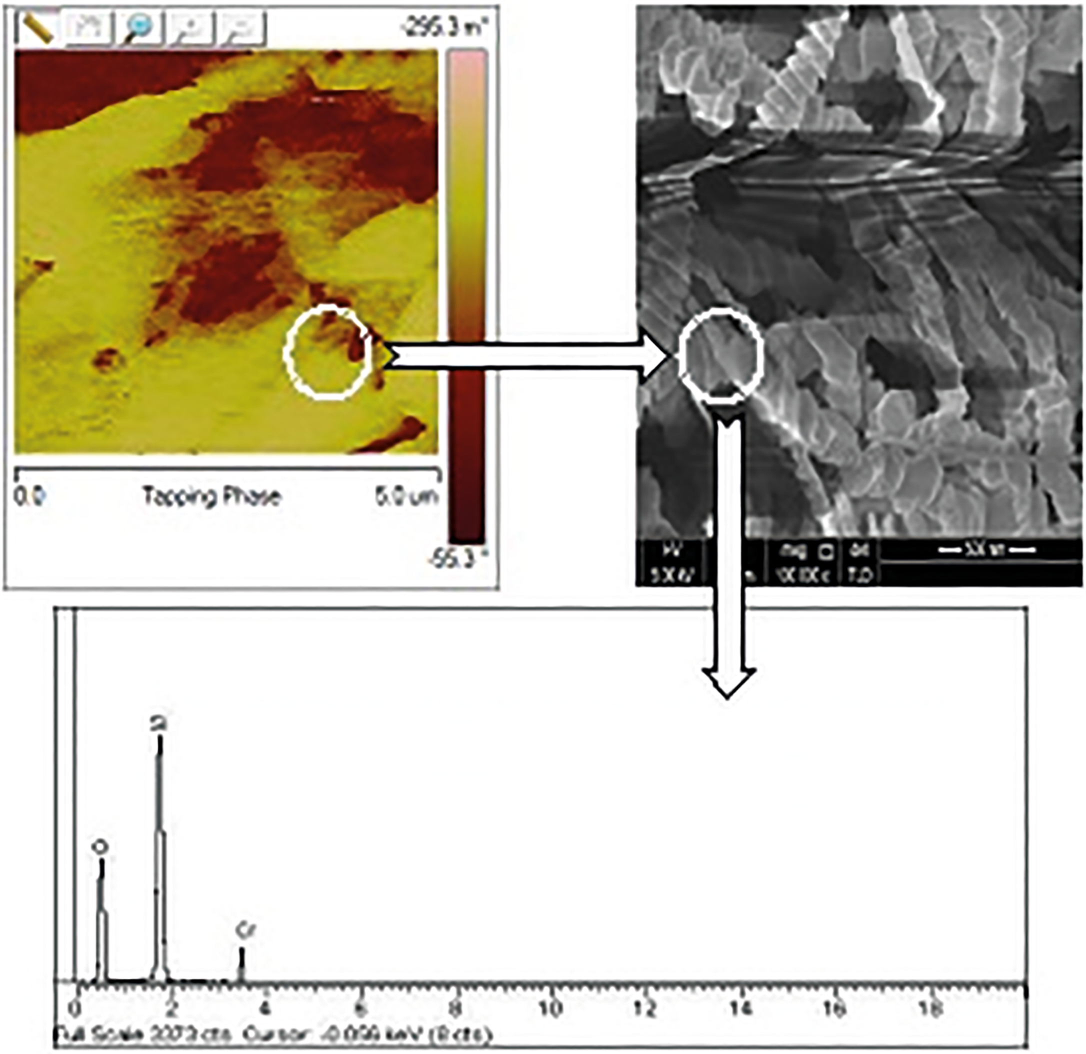


Figure 7. SEM of debris corresponding to the EDS and AFM.analysis of the wear particle at 15 N.

4. Conclusions

The tribological effect of Cr_2O_3 coating multi-layer under lubrication is investigated that contributed more understanding of quality and surfaces properties. The followings are outlined as:

1. Microstructure and hardness of Cr_2O_3- coatings were strongly associated with a thickness. Some structure of grains was clearly observed on the cross section of the polished surface.
2. At coating thickness 45 μm, the friction coefficient reduced from 0.29 to 0.24; and the wear rate was about $2.11X10^{-13}$ $m^3N^{-1}m^{-1}$while at coating thickness 15 μm, the friction reduced from 0.31 to 0.29 and the wear rate was about $2.73X10^{-13}$ $m^3N^{-1}m^{-1}$ at same coating thickness. The wear rate and coefficient of friction decrease as thickness increases then gradually decreases.
3. Three thicknesses of Cr_2O_3coatings, wear rate and friction coefficient was very low with a large thickness at lubricant. However, it showed high friction coefficient with a low thickness. The tribological properties of Cr_2O_3 coating has exhibited low friction characteristics and beneficial to improve the adhesion which was clear on worn surfaces at microstructure of Cr_2O_3-coatings.
4. The hardness increased from 102.5 HV to 116.4 ± 2.5 HV at coating thickness 45 μm, while hardness was increased from102.5 HV to 112.5 ± 3.5 HV at coating thickness 30 μm and from 102 ± 5 HV to 108 ± 3.5 HV at coating thickness 15 μm respectively.
5. Wear rate is strongly dependent on the components of the layer and the coating thickness. Brittle fracture was found, while adhesion and oxidation are the main mechanism of wear.

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