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Synthesis and characterization of Co-Mo alloy coating

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Abstract. Surface coating is very important in some applications. The preparation of Co-Mo alloy coating was prepared using electrodeposition process. The process of electrodeposition method was performed using 4 different concentration of molybdenum. The purpose of using different concentration of Mo in the solution bath is to find the optimum concentration of Mo that resulting to the best mechanical properties. The corrosion behavior, wear properties, surface morphologies and compositions of Co-Mo alloy was studied. The smooth surface was obtained when there was no Mo element in the solution bath. The Co-Mo coating that has the highest concentration of Mo, having the highest hardness value which is 286.6 HV. It was observed that the addition of Mo element in the deposit improved corrosion behavior of the deposits, hardness properties and resistance toward slurry erosion.

1. Introduction

Iron group commonly used as a source of magnetic materials [1]. The introduction of Mo elements in iron group material have the significant added value towards the magnetic properties [1]. Co-Mo alloy have the higher hardness and good corrosion resistance properties [1]. Co-Mo alloy coating have good strength, good corrosion resistance, good wear properties that can be applied to micro sensor, high force-force actuator and micro-electromechanical[2]. Surface coating is a technology that protects the surface of coated substrate from damage due to their application. Electrodeposition method is one of the finest techniques to produce Co-Mo alloy coating due to the low cost and simpler method to produce Co-Mo alloy coating [3]. Co-Mo alloy coating expected to be a good protective layer to improve wear, corrosion and hardness performance either in the mechanical, chemical and physical aspects. In this project, the wear properties of Co-Mo alloy coating were studied through the Slurry Erosion machine. The wear testing variable is the different concentration of Mo (33wt. %, 28wt. % and 23wt. %) at 500 rpm speed for 8 hours. The Co-Mo deposits were characterized through SEM and XRD. The corrosion behavior of the deposits was studied through Potentiodynamic polarization (PDP). The surface morphology of the Co-Mo deposits was analyzed using Surface measuring instrument (SURFTEST SV-600) machine was used to get the surface roughness. Finally, Vickers Microhardness tester was used to gain the hardness data of the Co-Mo alloy deposits.

2. Methodology

2.1. Sample preparation

Basically, there are two types of samples type 1 and type 2 as shown in Figure 1 which are 42.88cm2 and 59.2cm2 exposed areas respectively. Type 1 sample was made for the slurry erosion test that required maximum dimension of 2.54 cm x7.62 cm x 0.635 cm. Type 2 specimens was made for SEM, XRD, surftest and Vickers Microhardness testing. After the specimens cut into desired dimension,

then the sample grinded with two different grit of sandpaper. Firstly, the sample was grinded with 180 grit sandpaper. After that, the samples grinded with 400 grit sandpaper. The purpose of grinding is to eliminate the galvanize layer at the surface of the samples.

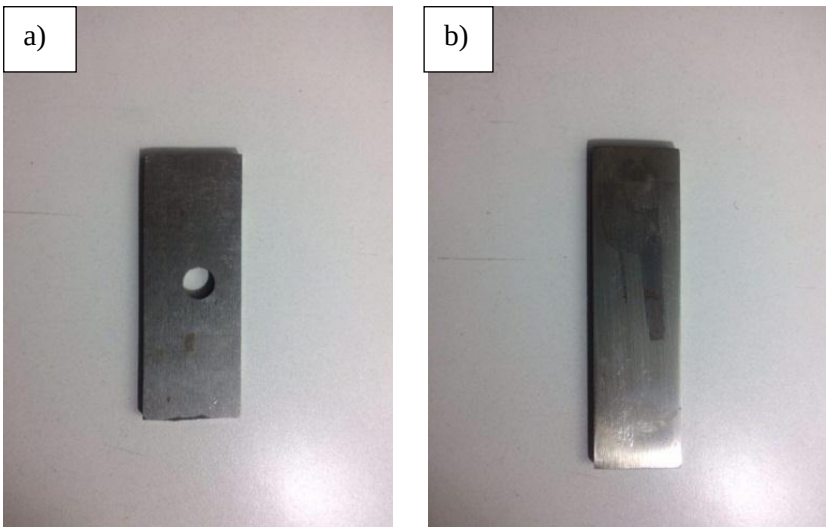

Figure 1. (a) Type 1 sample, and (b) Type 2 sample

2.2. Electrodeposition process

There are four type of solution with different concentration of Mo (0wt. %, 33wt. %, 28wt. % and 23wt. %) but with same concentration of Co for every solution that have been used while conducting the experiment. The preparation of the electrolytes bath has the same procedure. The magnetic stirrer will continuously stir the electrolyte bath until the end of the electrodeposition process. The temperature of the solutions is ±50˚c. The ph. Value of the solution is 2.9. The boric acid was use as ph. buffer. The electrolyte is prepared in 500 ml distilled water. The current is around 0.9-1.0A and carried out for 30 minutes deposition time. Table 1 shows the chemical composition of solution used in electrodeposition process.

Table 1. The chemical composition of solution used in electrodeposition process

	Mole	Weight(g)
Cobalt Sulphate, $CoSO_4 \cdot 7H_2O$	0.02	7.02
Molybdenum, Mo	0.03	3.50
	0.02	2.80
	0.02	2.10
Boric acid, H_3BO_3	0.13	8.24
Ascorbic acid, $C_6H_8O_6$	0.03	5.86
Saccharine	0.01	1.50

2.3. Characterization techniques

The Co-Mo alloy coating was characterized using theX-ray diffraction (XRD) analysis. The scan region (2Θ) was range from 30º to 100º at rate scan of 4˚ min^{-1}. The morphology of the Co-Mo alloy

deposits was studied using Scanning Electron Microscope (SEM). The SEM micrographs were taken with electron beam energy of 15keV.

2.4. Potentiodynamic polarization

The purpose of doing this testing is to obtain the corrosion behavior of the Co-Mo alloy coating. The specimens were attached to the electrical conductor wire using the wire glue. The purpose of this attachment is to enable the specimens fully immersed in the Phosphate Buffered Saline.

2.5. Vickers microhardness

Basically, Vickers Microhardness test is a testing to obtain the hardness values on the surface of the samples. The minimum and maximum load that available in the Vickers Microhardness machine is 10 g and 1 kg respectively. The load used for every sample is 1 kg. The reading was taken three times of the different spot of Co-Mo alloy coating sample to obtain average value.

2.6. Surface roughness

Surface roughness testing used to gain knowledge about the surface roughness of Co-Mo alloy coating on the samples. Surface roughness machine that available in the lab is Mitutoyo Surface measuring instrument (SURFTEST SV-600). The accurate procedure of this surface roughness testing is to take 3 different readings from 3 different spots on the sample. The purpose of taking the 3 different reading is to get the average value of the surface roughness value.

2.7. Slurry erosion

The specimen dimension for this slurry erosion wear test is 76 mm x 25 mm x 6 mm. Rotation speed of 500 rpm was for 8 hour with 2 hours' time interval for data collection. Mining sands with particles size of 710 µm were used in slurry erosion test.

3. Results and discussion

3.1. XRD analysis

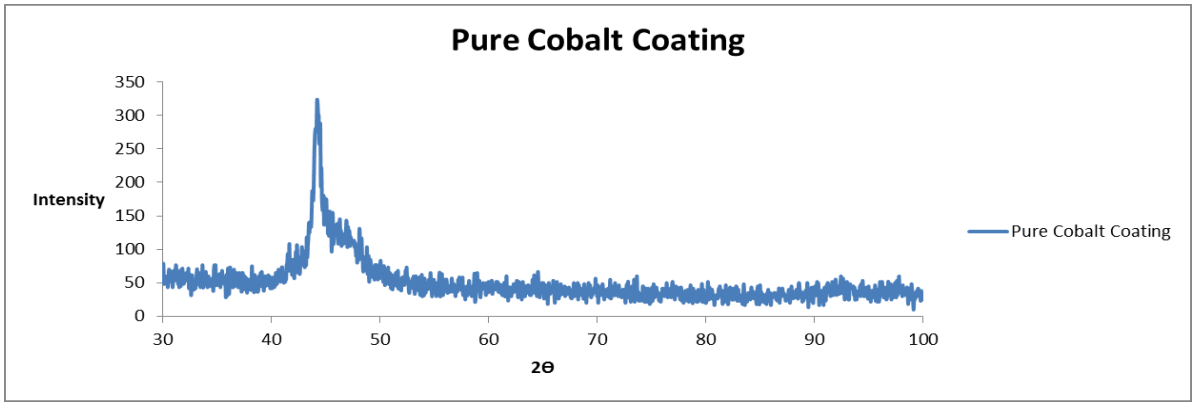

Figure 2. XRD pattern of pure cobalt coating.

The structural analysis of Co-Mo alloy deposits was performed using XRD. Based on the result obtained, the pure cobalt deposits and Co-Mo deposits show similar pattern of peak. Figure 3.1 –

Figure 3.4 shows the result of the XRD obtained from the Co-Mo alloy deposits. Pure Co and Co-Mo coating samples showed the peaks of Co and Co-Mo after referring to the theta values with the XRD library data for Co-Mo. The pure Co deposits rich with close-packed hexagonal structure [4]. The only phase detected in pure Co coating is close-packed hexagonal structures (hcp) which are hcp (100) at 2θ = 41.58º, hcp (002) at 2θ = 44.50º, hcp (101) at 2θ = 47.44º and hcp (112) at 2θ = 92.44º. For the Co-Mo deposits (23-33 wt. %), the diffraction peaks of Mo at 2θ = 40.51 º, 58.60 ºand 73.66 º correspond to (110), (200) and (211) plane structure. However, the diffraction of Mo peaks very hard to obtain using electrodeposition method. The more content of Mo in the Co-Mo deposits shift the peaks of Mo towards the lower diffraction [5].

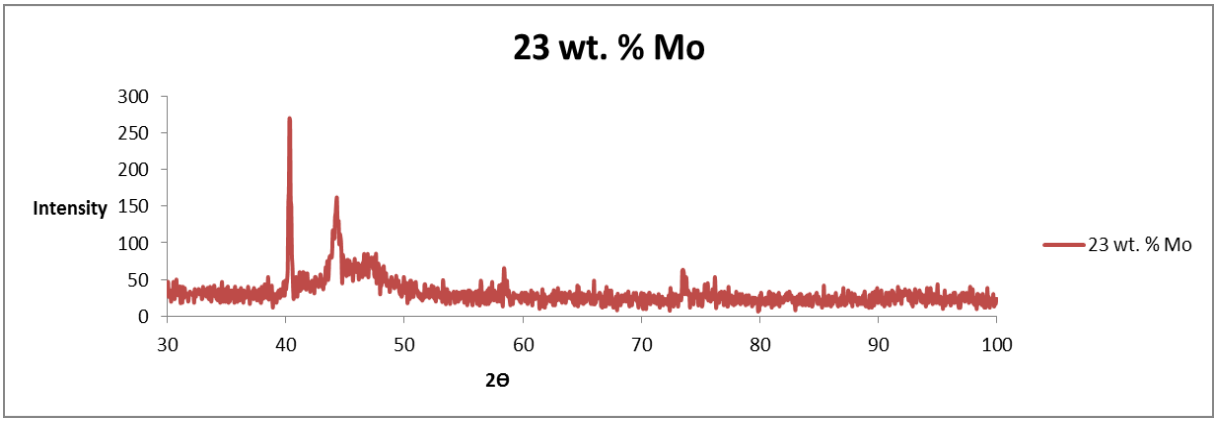

Figure 3. XRD pattern of Co-Mo alloy coating with 23wt. % Mo.

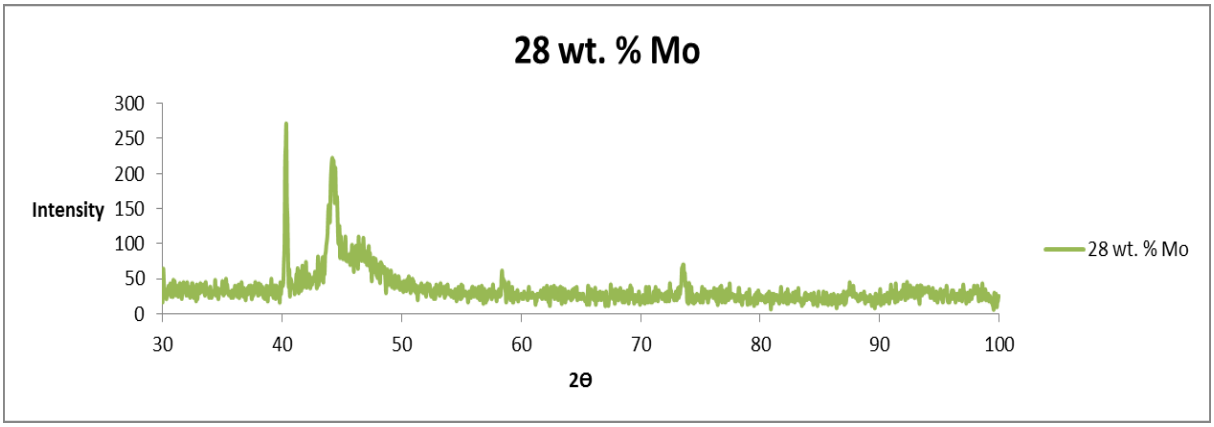

Figure 4. XRD pattern of Co-Mo alloy coating with 28wt. % Mo.

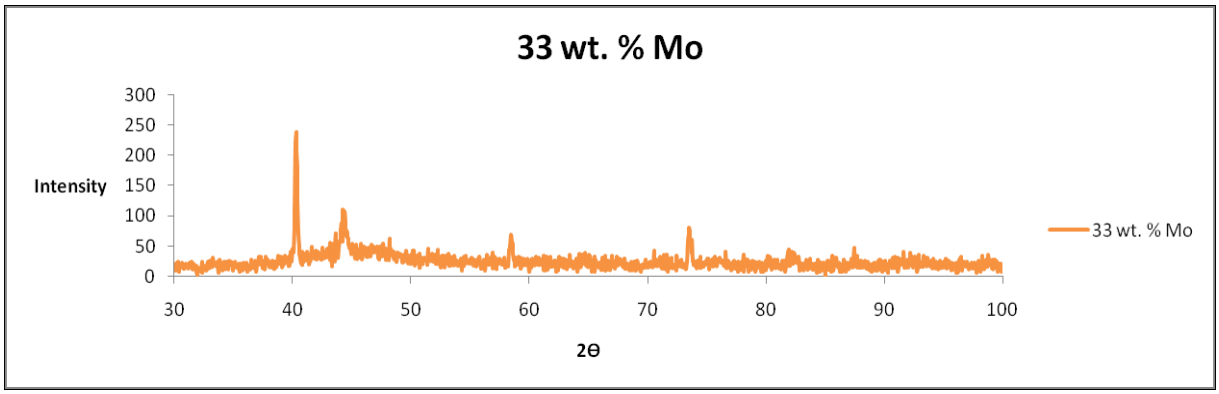

Figure 5. XRD pattern of Co-Mo alloy coating with 33wt. % Mo.

3.2. Scanning electron microscopy (SEM)

Figure 3.5 shows the micrograph of pure Co and Co-Mo deposits obtained through SEM. Based on the SEM results, the Co-Mo deposits that content the highest concentration of Mo (33 wt. % Mo) show finest grain and crack free surface morphology compared with the other Co-Mo deposits. Besides, the particles distribution of Co-Mo deposits in the highest Mo content seemed to be uniform distribution compared to the other Co-Mo deposits. The Co-Mo deposits with the lowest Mo content show poor distribution of particles. The Co-Mo deposits with the moderate concentration of Mo (28 wt. %) show very coarse surface morphology. The pure Co deposits show cracks on the surface morphology while the surface morphologies after adding Mo are crack-free. These results are consistent with previous research [6].

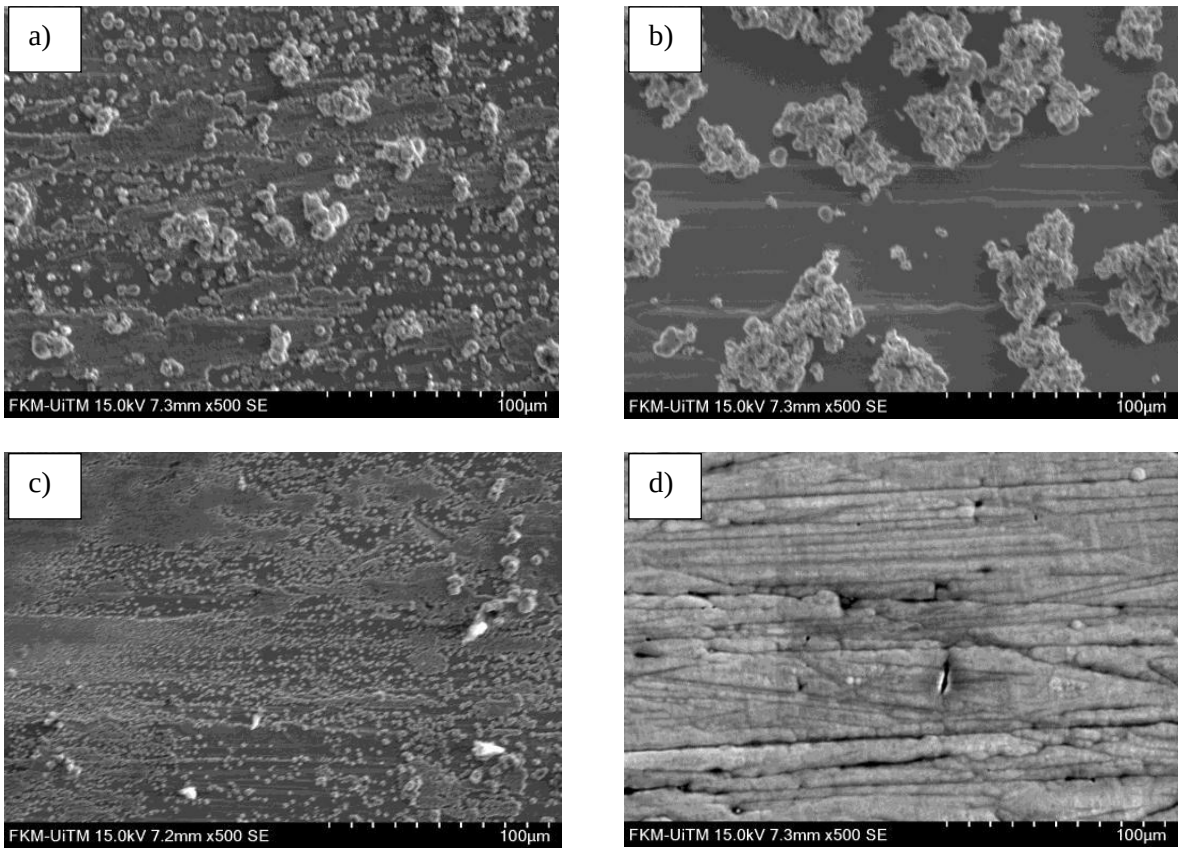

Figure 6. (a) 23 wt. % Mo, (b) 28 wt. % Mo, (c) 33 wt. % Mo, (d) Pure Co

3.3. Vickers microhardness

The Microhardness of the samples was taken for 3 times at different spots of the deposits to ensure the average reading were taken. Figure 3.6 show the Vickers Microhardness value of pure Co deposits and Co-Mo deposits with different concentrations of Mo. Based on the Vickers Microhardness results, the highest Microhardness value was obtained at 33 wt. % Mo while the lowest Microhardness value was obtain at pure Co deposit. The Co-Mo deposits with the lowest Mo content show the second highest of Microhardness value. The highest value of Microhardness obtained in 33 wt. % Mo was due to the finer surface morphology as shown in previous SEM sub-topic. The fine surface morphology improved the value of Microhardness [4]. The Co-Mo deposits have good hardness properties depending on the surface morphology and the concentration of Mo content in the deposits [7] [8].

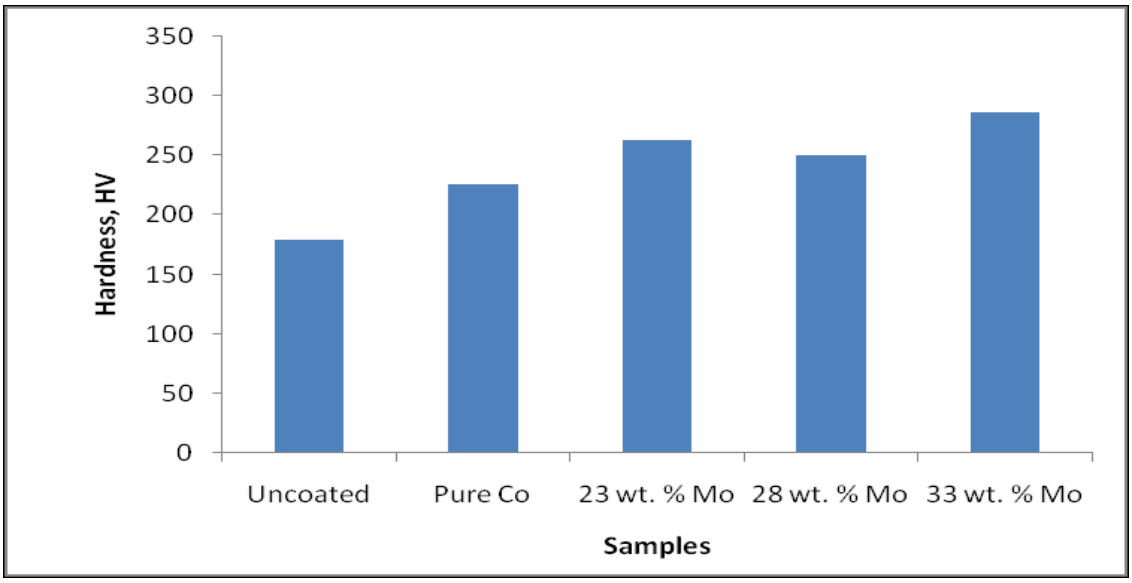

Figure 7. Vickers Microhardness value for different concentrations of Mo.

3.4. Potentiodynamic polarization

Figure 3.7 show the Potentiodynamic polarization (PDP) curves of different concentrations of Mo. The Co-Mo deposits that contain the highest concentration of Mo show the best corrosion resistance. This is shown as the corrosion potential of 33 wt. % Mo is the highest and the corrosion current is the lowest as shown in Table 3.1. This is because of the formation of thin passive film which increases the corrosion resistance [9]. The pure Co deposits show the poorest corrosion resistance as corrosion potential is the lowest. The corrosion rate of the Co-Mo deposits decrease as the molybdenum content increase [2]. However, the corrosion resistance of Co-Mo deposits in 23 wt. % Mo is better than in 28wt. %. This can be suggested that, the addition of Mo element in the deposits gave the significant added value towards corrosion resistance, but at the same time the surface morphology also play the main role in the corrosion properties [2] Co-Mo deposits that content 28 wt. % Mo show the worst corrosion resistance compared to deposits with 23 wt. % Mo resulting from the coarsest surface

morphology as shown in SEM. However, Co-Mo alloy coating have the good corrosion resistance depending on the concentration of Mo content and surface morphology [10].

3.5. Surface roughness

Figure 3.8 show the average surface roughness of different concentrations of Mo. The reading of the surface roughness was taken for three times at different spots to get the average values of surface roughness of the deposits. It was observed that, the surface roughness was varied for different concentrations of Mo. The pure Co deposits show the lowest surface roughness (Ra = 0.306) due to its finest surface morphology and uniform particles distribution. Although the pure Co deposits show the good surface roughness, however the surface also shows the crack films. Meanwhile, out of all of the deposits with Mo, the Co-Mo deposits (33 wt. % Mo) show the lowest surface roughness. This is because the surface morphology for this particular deposit is the finest as shown in SEM. Co-Mo deposits with the moderate content of Mo (28 wt. %) show the poorest surface roughness result (Ra = 6.47). This is due to the ununiformed distribution of particles and very coarse grains as shown in SEM. The surfaces structure of the deposits affected the result of the surface roughness of the deposits. The finest surface morphology improved the surface roughness value.

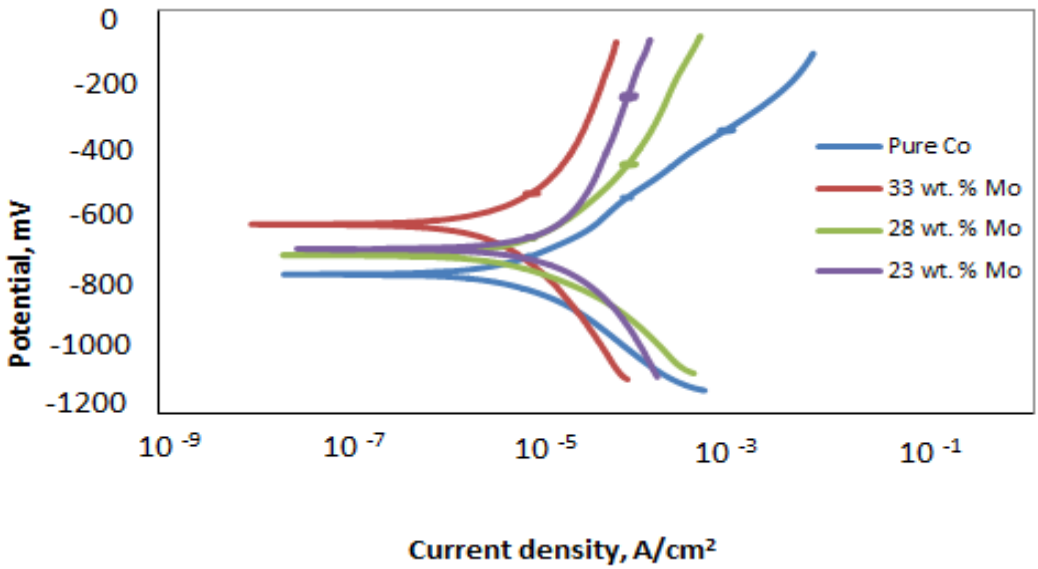

Figure 8. Potentiodynamic polarization curves of different concentrations of Mo.

3.6. Surface roughness

Figure 3.8 show the average surface roughness of different concentrations of Mo. The reading of the surface roughness was taken for three times at different spots to get the average values of surface roughness of the deposits. It was observed that, the surface roughness was varied for different concentrations of Mo. The pure Co deposits show the lowest surface roughness (Ra = 0.306) due to its finest surface morphology and uniform particles distribution. Although the pure Co deposits show the good surface roughness, however the surface also shows the crack films. Meanwhile, out of all of the deposits with Mo, the Co-Mo deposits (33 wt. % Mo) show the lowest surface roughness. This is because the surface morphology for this particular deposit is the finest as shown in SEM. Co-Mo deposits with the moderate content of Mo (28 wt. %) show the poorest surface roughness result (Ra = 6.47). This is due to the ununiformed distribution of particles and very coarse grains as shown in SEM. The surfaces structure of the deposits affected the result of the surface roughness of the deposits. The finest surface morphology improved the surface roughness value.

3.7. Slurry erosion

Figure 3.9 show the result the slurry wear test for different concentrations of Mo. The moderate rotation speed used for the slurry erosion test was 500 rpm. The moderate rotation speed was used in order to get the most optimum concentration of Mo with the best wear properties. The erosion wear rate (mass loss of deposits) increases with time [11]. The result of slurry erosion test shows the similar trend of curve as previous research [12]. The result from the slurry wear test shows that, the deposits with the highest amount of Mo content (33 wt. % Mo) show the least mass loss which is 0.0833g. The pure cobalt also shows great wear properties as the mass loss of deposits is 0.0861g. The mass loss of deposits through the slurry erosion test is related to the surface roughness of the deposits. The poorest surface morphology (28 wt. % Mo) show the most mass loss of deposits through slurry erosion test. The finest surface roughness tends to good in terms of wear properties. However, the addition of Mo into the Co based deposits gave the significant added value toward the wear properties [13].

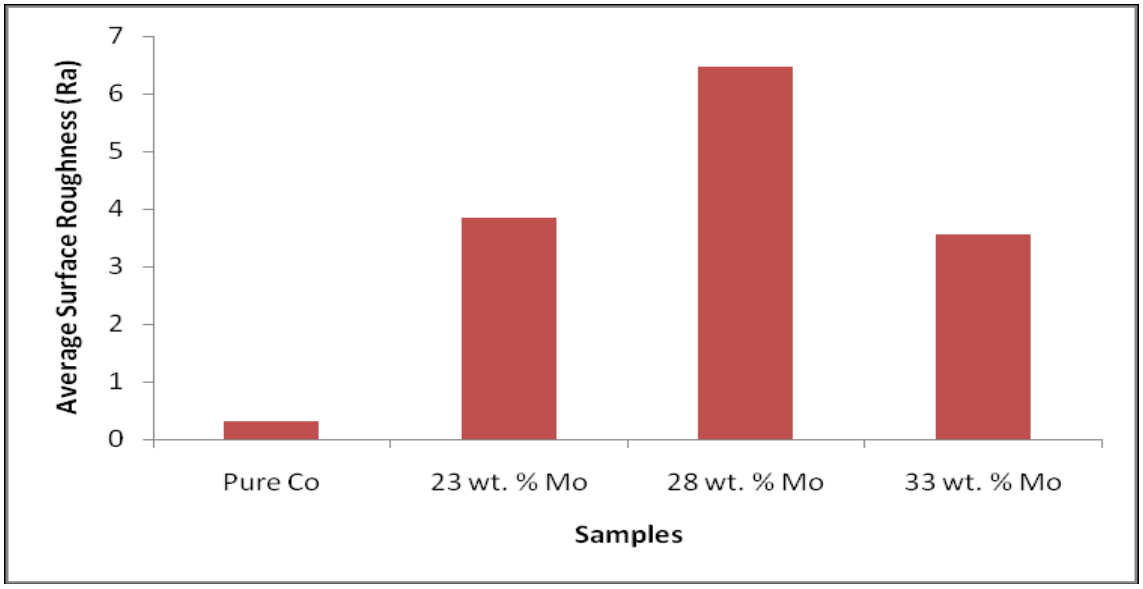

Figure 9. Average surface roughness for different concentrations of Mo.

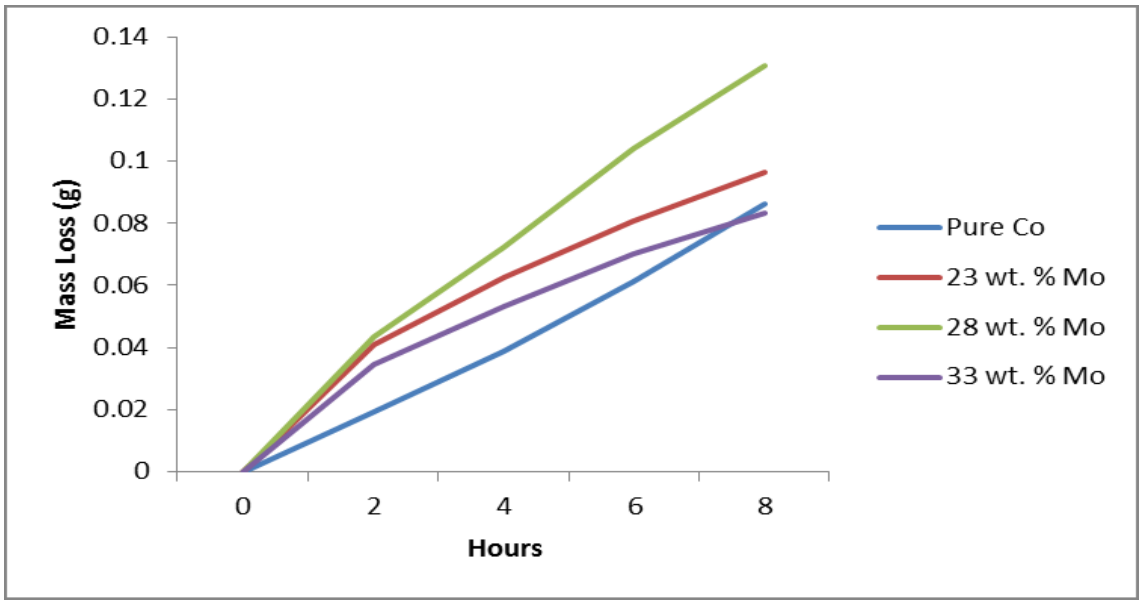

Figure 10. Slurry wear test comparison for different concentrations of Mo.

4. Conclusions

Based on the result obtained from the study, the addition of Mo gave the significant added value toward the surface morphology, corrosion resistance, hardness and wear properties of Co-Mo alloy coatings. The Co-Mo alloy deposits with the highest Mo content (33 wt. % Mo) show fine surface morphology obtained from SEM resulting good corrosion resistance, good hardness properties and good wear resistance.

The surface coating of Co-Mo alloy improved the actual hardness of the uncoated mild steel. The actual Vickers Microhardness of the uncoated mild steel is 179.67 HV. As the Co-Mo alloy coating was coated the mild steel, the Vickers Microhardness values was increased as the increased of Mo content in the Co-Mo coating. The highest Vickers Microhardness was obtained in 33 wt. % Mo which is 286.6 HV. Surface roughness of every Co and Co-Mo deposits was different according to the Mo content in the deposits. The pure Co deposit was the lowest surface roughness of 0.306 Ra while the 28 wt. % Mo deposits was the highest surface roughness of 6.47 Ra.

The Co-Mo deposits that contain the highest concentration of Mo show the best corrosion resistance. This is shown as the corrosion potential of 33 wt. % Mo is the highest and the corrosion current is the lowest. The corrosion rate of the Co-Mo deposits decrease as the molybdenum content increase. However, the surface morphology also affects the corrosion behavior of Co-Mo deposits. Least coating mass loss was obtained in the 33 wt. % Mo deposits while the highest coating mass loss was obtained at in the 28 wt. % Mo deposits. This is due to the finest surface morphology obtained in 33 wt. % Mo that improved the wear resistance of the deposits.

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