Role of different coating materials and coating thickness on velocity and displacement discontinuities in a tribo-system

Salim Sharieff, S. Ranganatha, Shiv Pratap Singh Yadav, Nadeem Pasha K

Abstract*: In any tribo-system, same load is transferred between two contacting surfaces. The stress state within one element of contacting surface depends on the mechanical properties of material like young's modulus. The displacement and velocity were found to exhibit discontinuity. The discontinuity in displacement and velocity were found to be dependent on coefficient of friction. A set of experiments were conducted for understanding this phenomenon of dependency of co-efficient of friction and discontinuities in displacement and velocity using pin-on-disc test rig. For obtaining different set in displacement and velocity discontinuities coatings of enamel, zinc, aluminium and molybdenum coatings were coated on mild steel pin. Coating thickness were 100 microns 200 microns and 300 microns for each coating materials. Pin-on-disc test were carried off with a normal load of 30 newton and speed of 500 rpm. Scanning electron micrographic study were carried out on wornout surfaces. In general, the coefficient of friction was found to increase with increase in coating thickness for all coating materials i.e. enamel, zinc, aluminium and molybdenum. The results indicated that the extent of damages on wornout coatings which depends on existing discontinuous in displacement and velocities across sliding pair were found to depend on observed coefficient of friction.

***Key words*: Coating damages, Displacement discontinuity, Extrusion, Velocity discontinuity.**

I. INTRODUCTION

Metallic materials in particular iron and its alloys are extensively used in industrial applications. The alloys of iron after heat treatment exhibit improved mechanical properties in particular hardness and toughness. In automobile industries power is transmitted through gear systems. The tractive force which gets transmitted from source of development of energy to the location of its utility through gear systems. Varieties of gear systems are designed to improve the efficiency of power transmission. The surface of gear teeth is subjected to severe state of stress and fatigue. The relative motion which exhibits which exist between two mating gear tooth will introduce displacement discontinuity and velocity discontinuity. The contact between two gear tooth can be generalized as tribo problem. In all mechanical systems where ever relative motion is involved leads to tribo effects. These tribo effects leads to power loss, component damage and loss in operation utility due to downtime. In extreme condition that tribo effect leads to complete breakdown of machinery. All these ill effects of tribo phenomenon leads to inefficiency of machineries. Efforts have been made by different researchers to overcome the ill effects of tribo phenomenon. The ill effects of tribo phenomenon are frictional forces and wear of materials.

In tribosystem the load transferred from one element of the pair to the other element of the pair is same. The stress state at all the contact will be different for different mating elements of the pair. The displacement and velocity are discontinuous at the interface of the meeting surface of tribosystem. Co-efficient of friction and wear during relative motion are found to be related to velocity and displacement discontinuities. Various authors have made attempt for improving wear life by manipulating velocity and displacement discontinuity using pair of mating elements having wide range of hardness and also manipulated the velocity and displacement discontinuity giving variety of coatings on the mating elements of tribo-system. Bonny et al, conducted experiment for evaluating way of WC-Co based materials using pin on plate system. They varied the parameters like normal force, accelerating velocity and sliding distance. They found marked increase in wear as the load increased but friction was decreased. Increase in oscillation speed increase both friction and wear [1]. Kennady and Hashmi, conducted experiments for evaluating tribo behaviour of coated and uncoated materials. Sliding wear, erosion, impact and dynamic wear test was carried out. In particular, they found out that higher loads and shorter duration of experiment is required for characterization of thin coatings [2]. Hee Ay Ching et all, reviewed the literature on coatings employed in orthopaedic implants. They concluded that biocompatible Ta coated implants are related as best in joint prosthesis applications. The ratio of hardness in elastic modulus was found to be an important parameters influencing wear performance of coating materials. A system were in a strong adhesion and good quality of coatings were found to be good for contact stress, friction and wear [3].

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Yihong Liu et all, conducted test using ball on plate test rig for evaluating performance of self-glazed zirconia on tooth.

They concluded that zirconia coatings are comparable with natural tooth surface as far as aesthetic appearance [4].

Srinivasa Prakash Regalla et all, made attempt for understanding zinc of metal coatings in solid lubrications. Experiments were conducted using pin on disc test rig where in the pin was coated with zinc coatings. They found that for better utility of zinc coating a bonding agent between zinc coating and steel pin was essential [5]. Deepak Rajput et all, made attempt to evaluate performance of molybdenum on chromium dual coating on steel. They conducted experiments for erosion according to ASTM G76 and sliding wear test according to a ASTM G77. They found that chromium coating performed good in erosion environment while molybdenum on chromium performed better in sliding wear [6]. Dagmar Jakubeczyova et all, made attempt for evaluating wear performance chromium based coatings. Experiments were conducted using pin on disc test rig. They found that wear track morphology was dependent on hardness [7]. Jeehoon Ahn et all, made attempt to understand wear performance of plasma- sprayed molybdenum blend coatings. Pin on disc test rig was employed for testing. They found that wear loss increased with increasing normal load. Further they observed that blended coatings exhibited better wear performance compared to pure molybdenum coatings though the hardness was lower [8]. Sristtayakul et all, made attempt on evaluating performance of hard chromium and MoN stainless steel. Experiments were conducted according to a ASTM G133-05 standard. The result of the experiment were that MoN-HC exhibited higher wear resistance compared to HC [9]. Sylwia Wojda et all, made attempt for understanding tribological behaviour of enamel material. They conducted experiment using pin on disc test rig. They found that composite materials performed better compared to others [10]. Vencl et all, made attempt for understanding hardfaced and thermal sprayed coatings. Conducted experiments using pin on disc test rig. They concluded from results that nickel based coatings are better when compared to iron based coatings. They also observed the wear performance was also dependent on type and morphological features of WC reinforcing particles [11]. Illaiyavel and Venkatesan, made attempt for understanding wear behaviour manganese phosphate coated steel. Experiments were conducted using pin on disc test rig. The result showed that heat treated manganese phosphate with oil lubricated performed better [12]. Bacahar et all, Amitava Majumdar and Sunirmal, Vneet Shibe and Vikas Chawla, Popoola et all, Praveen and Venkatesha, Fayomi and Popoola, Giovanni Fortese et all and Abdul Hossain et all, made attempt in characterizing the metallurgical bonding of different coating systems [13], [14], [15], [16], [17], [18], [19] and [20].

In the present Investigation a basic study has been carried out for understanding effects of coating. Experiments in the lab have been carried out using pin on disc tribo-system. Disc was made out of En 31 hardened steel. Mild steel coated with different coatings was slid against disc. Coatings like enamel, pure zinc, pure aluminium and pure molybdenum wear coated on mild steel pin.

II. EXPERIMENTAL DETAILS

The mild steel pin specimen prior to machining, were cut out of steel rod (dimensions: height 30cm, diameter 15mm) to pieces of approximate in length 30-35mm. These pieces were machined on lathe. Turning on Lathe was performed to decrease the diameter from 15mm to 8mm. Facing on lathe was performed to reduce the height of the workpiece from 34mm to 30mm. The dimensions of the pin used in experiment are shown in the Fig.1. The Pin-on-disk equipment is as shown in Fig.2.

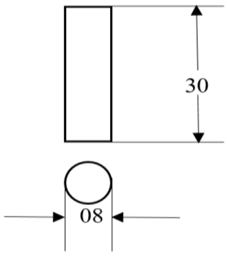


Fig.1: Dimensions of the pin used in mm.

Fig.2: Pin holder and disk.

The mild steel pin specimen was coated with enamel, pure zinc, pure aluminium coating with different thickness of 100 microns, 200 microns and 300 microns. Molybdenum coating with thickness were 200 microns, 250 microns and 300 microns. The coating was carried out by thermal spray coating method. The pin specimen which was coated with various coatings like enamel, pure zinc, pure aluminium and pure molybdenum with different thickness were tested on pin on disc wear testing machine. Pin on disc wear testing machine has disc diameter of total 160mm, there are variety of holders designed for different size and shape of pins. The holder used in the present experiment can holds a pin of 8mm in diameter and 30mm in height. The test rig has a display device which displays amount of wear, friction, speed, temperature and time (sec/ rev). The data like wear, frictional force, co-efficient of friction were recorded in a personal computer. The software for recording data is WINDUCOM. The WINDUCOM software was supplied by pin-on-disk test rig manufacturer. The test details like load, time and speed of experiments are given in Table I.

Table I: Test details of experiments.

Sl No.	Coating material	Load in newton	Time in seconds	Speed in rpm
1.	Enamel	30	30	500
2.	Enamel	30	30	500
3.	Enamel	30	30	500
4.	Zinc	30	30	500
5.	Zinc	30	30	500
6.	Zinc	30	30	500
7.	Aluminium	30	30	500
8.	Aluminium	30	30	500
9.	Aluminium	30	30	500
10.	Molybdenum	30	240	500
11.	Molybdenum	30	240	500
12.	Molybdenum	30	240	500

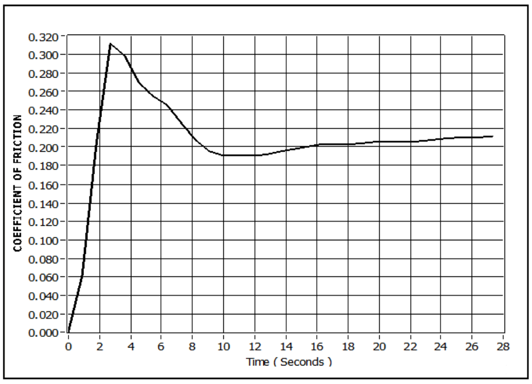
III. REULTS AND DISCUSSION

Mild steel pins coated with enamel, pure zinc, pure aluminium and pure molybdenum were slid against En 31 hardened steel disc using pin on disc test rig equipment according to ASTM.

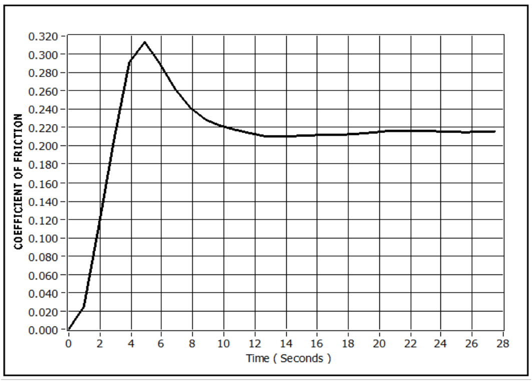
A. Enamel coating

Enamel coating thickness of 100 microns, 200 microns and 300 microns were coated on mild steel pins. Frictional force and normal forces were monitored during sliding experiment. The co-efficient of friction was estimated using monitored frictional force and normal force. The typical plots of co-efficient of friction versus sliding time are shown in Fig. 3.

(a)



(b)



(c)

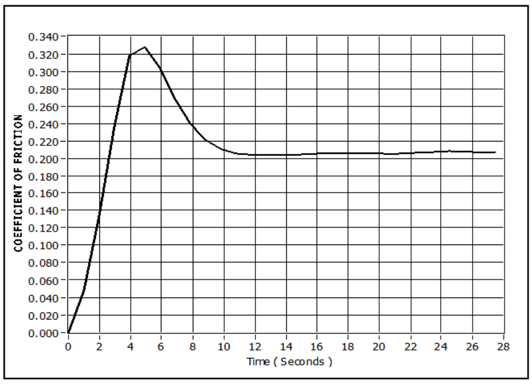


Fig.3: Dependency of co-efficient of friction with respect to sliding time for different coating thickness of Enamel (a) 100 microns; (b) 200 microns; (c) 300 microns.

Fig.3a shows the dependency of co-efficient of friction with sliding time for enamel coating thickness of 100 microns. The co-efficient of friction increased from nil to approximately 0.31 when pin was slid from rest to over a time of 2.5 seconds then gradually decreased from 0.31 to around 0.21 when pin was further slid over a period up to 10 seconds. The co-efficient of friction stabilized with magnitude 0.21 after approximately 10 seconds.

Fig.3b shows the dependency of co-efficient of friction with sliding time for enamel coating thickness of 200 microns. The co-efficient of friction increased from nil to approximately 0.31 when the pin was slid from rest over a time of 5 seconds then gradually decreased from 0.31 to around 0.21 when pin was further slid over a period up to 12 seconds. The co-efficient of friction stabilized with magnitude 0.21 after approximately 12 seconds.

Fig.3c shows the dependency of co-efficient of friction with sliding time for enamel coating thickness of 300 microns. The co-efficient of friction increased from nil to approximately 0.32 when the pin was slid from rest over a time of 5 seconds then gradually decreased from 0.32 to around 0.21 when pin was further slid over a period up to 12 seconds. The co-efficient of friction gets stabilized with magnitude 0.21 after approximately 12 seconds.

The co-efficient of friction data from figure 3 were used for estimating average co-efficient of friction. The estimated average co-efficient of friction for different coating thickness of enamel are tabulated in Table II.

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Table II: Average co-efficient of friction for different coating thickness of enamel.

Sl No.	Coating thickness in microns	Co-efficient of friction
1	100	0.20
2	200	0.21
3	300	0.21

The data in Table II is used for plotting the graph showing the dependency of co-efficient of friction on coating thickness for enamel coating when slid against En 31 hardened steel.

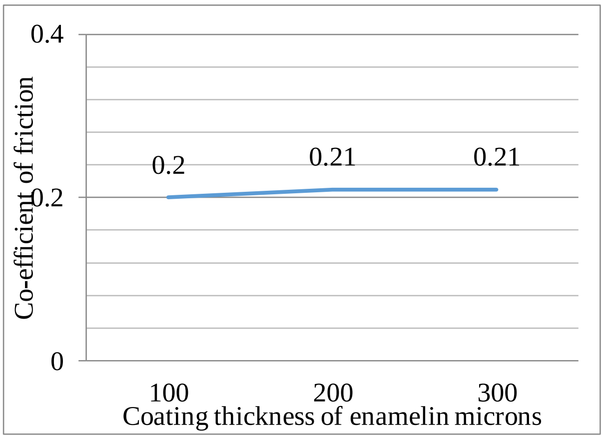
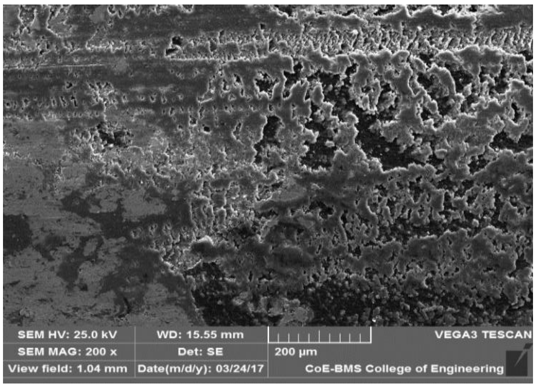


Fig.4: Co-efficient of friction against coating thickness of enamel.

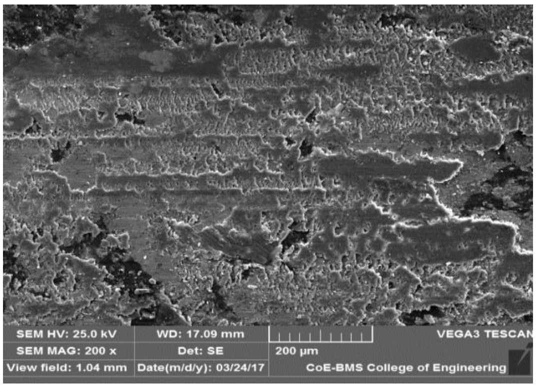
Fig.4 shows the dependency of coefficient of friction with coating thickness of enamel. The coefficient of friction was found to be 0.20 for enamel coating thickness of 100 microns. The coefficient of friction was found to be 0.21 for both enamel coating thickness of 200 microns and 300 microns. The study of dependency of coefficient of friction with respect to coating thickness of enamel indicates that as the coating thickness increased from 100 microns to 200 microns, the coefficient of friction was also increased. Further results indicate that the coefficient of friction gets stabilizes to a value of 0.21 though the thickness increased from 200 microns to 300 microns.

Scanning electron micrographic studies have been carried out on worn enamel coated pin surfaces for understanding the dependency of coefficient of friction with different coating thickness of enamel as shown in Fig.5.

(a)



(b)



(c)

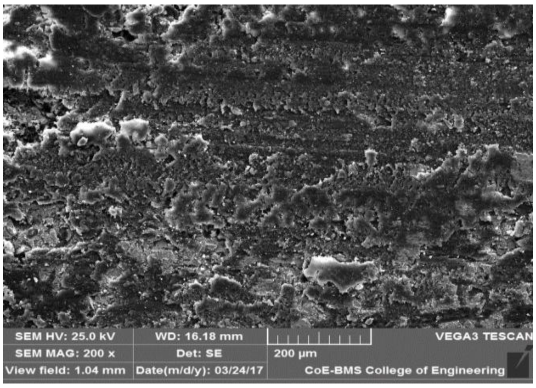
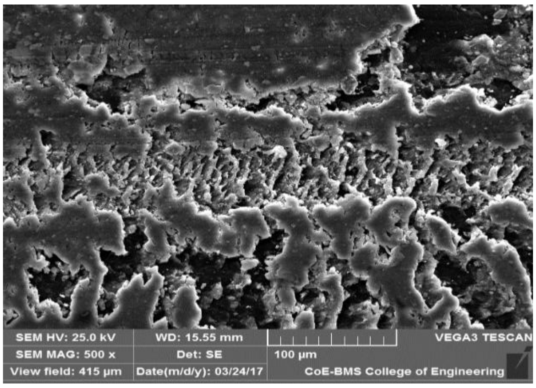


Fig.5: Micrograph of enamel coated pin surfaces at a magnification of 200x (a) 100 microns; (b) 200 microns; (c) 300 microns.

Micrograph of Fig.5a, 5b and 5c are correspond to respectively enamel coating thickness of 100 microns, 200 microns and 300 microns at a magnification of 200x.

The morphology of micrograph in Fig.5a shows larger extent of non-uniform coating damage when compared to micrograph in Fig.5b and Fig.5c. The non-uniform coating damage is attributed to observed coefficient of friction.

(a)



(b)

(c)

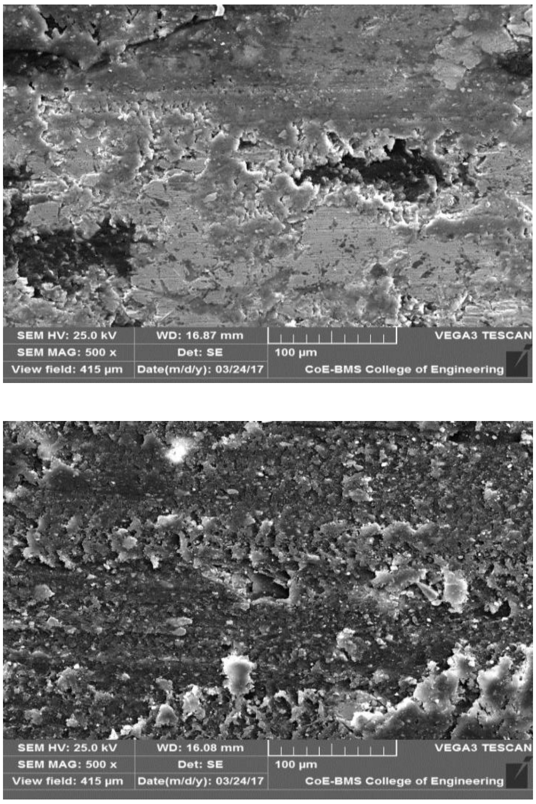


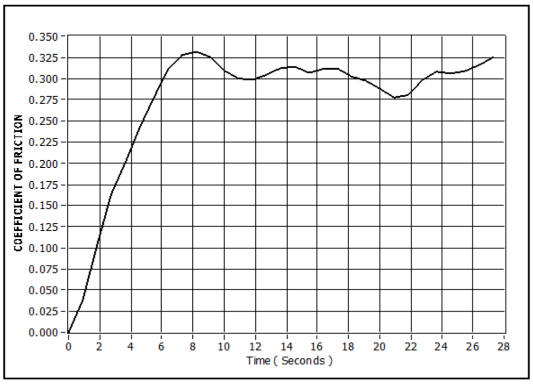
Fig.6: Micrograph of enamel coated pin surfaces at a magnification of 500x (a) 100 microns; (b) 200 microns; (c) 300 microns.

Worn surfaces for better clarity, were studied in scanning electron micrograph at a higher magnification i.e., 500x. Fig.6 shows the Micrograph of worn enamel coated pin surfaces. Micrograph of Fig.6a, 6b and 6c are correspond to respectively enamel coating thickness of 100 microns, 200 microns and 300. The morphology brings out more clarity of the extent of non-uniform coating damage.

B. Zinc coating

Zinc coating thickness of 100 microns, 200 microns and 300 microns were coated on mild steel pins. Frictional force and normal forces were monitored during sliding experiment. The co-efficient of friction was estimated using monitored frictional force and normal force. The typical plots of co-efficient of friction versus sliding time are shown in Fig.7.

(a)



(b)

(c)

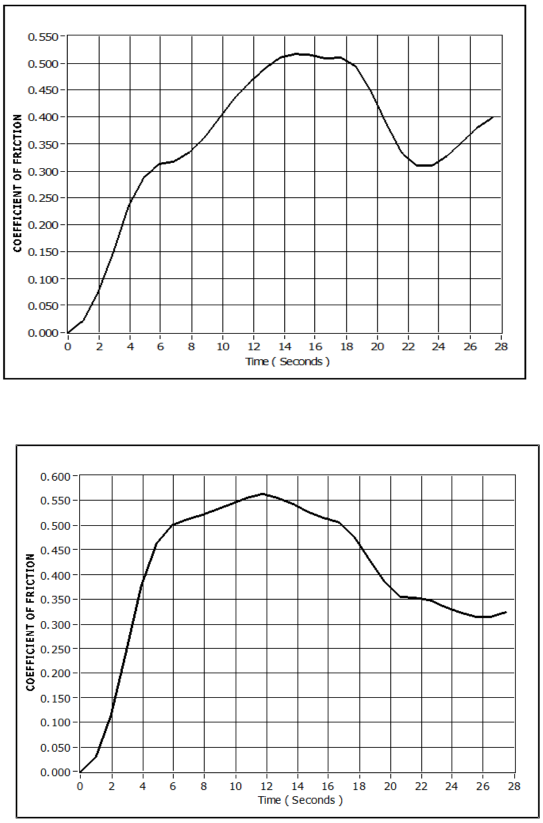


Fig.7: Dependency of co-efficient of friction with respect to sliding time for different coating thickness of zinc (a) 100 microns; (b) 200 microns; (c) 300 microns.

Fig.7a shows the dependency of co-efficient of friction with sliding time for zinc coating of thickness 100 microns. The co-efficient of friction increases from nil to approximately 0.33 when the pin was slid from rest to over a time of 8seconds. Then co-efficient of friction was almost stabilized with magnitude 0.30 after approximately 8seconds.

Fig.7b shows the dependency of co-efficient of friction with sliding time for zinc coating of thickness 200 microns. The co-efficient of friction increases from nil to approximately 0.52 when the pin was slid from rest to over a time of 16 seconds. After that it started decreasing and a local minima was seen at about 22 seconds of sliding distance. Then co-efficient of friction was almost stabilized with magnitude 0.35 after approximately 22seconds.

Fig.7c shows the dependency of co-efficient of friction with sliding time for zinc coating of thickness 300 microns. The co-efficient of friction increases from nil to approximately 0.56 when the pin was slid from rest to over a time of 12 seconds. After that it decreased to 0.25 at about 22 seconds of sliding distance. Then co-efficient of friction was almost stabilized with magnitude 0.35 after approximately 22seconds.

The co-efficient of friction data from Fig.7 were used for estimating average co-efficient of friction. The estimated average co-efficient of friction for different coating thickness of zinc are tabulated in Table III.

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Table III: Average co-efficient of friction for different coating thickness of zinc.

Sl No.	Coating thickness in microns	Co-efficient of friction
1	100	0.31
2	200	0.40
3	300	0.46

The data in Table III is used for plotting the graph showing the dependency of co-efficient of friction on coating thickness for zinc coating when slid against En 31 hardened steel.

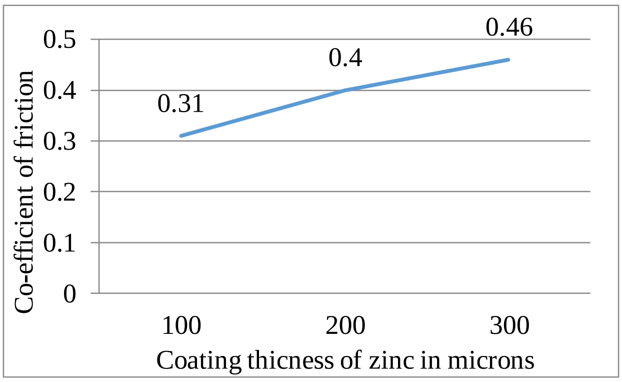
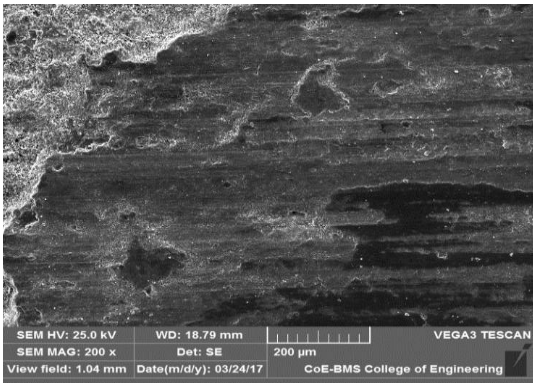


Fig.8: Co-efficient of friction against coating thickness of zinc.

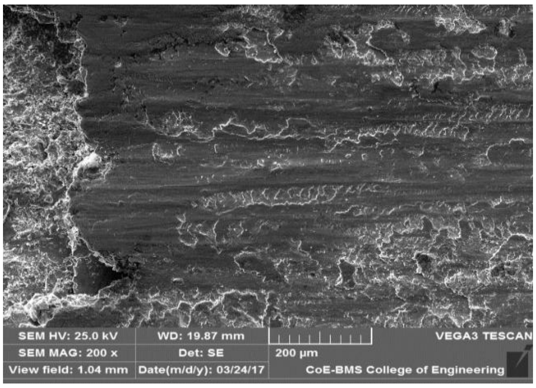
Fig.8 shows the dependency of coefficient of friction with coating thickness of zinc. The coefficient of friction was found to be 0.31, 0.41 and 0.46 respectively for zinc coating thickness of 100 microns, 200 microns and 300 microns. The coefficient of friction was found increase with increase in zinc coating thickness.

Scanning electron micrographic studies have been carried out on worn zinc coated pin surfaces for understanding the dependency of coefficient of friction with different coating thickness of zinc as shown in Fig.9.

(a)



(b)



(c)

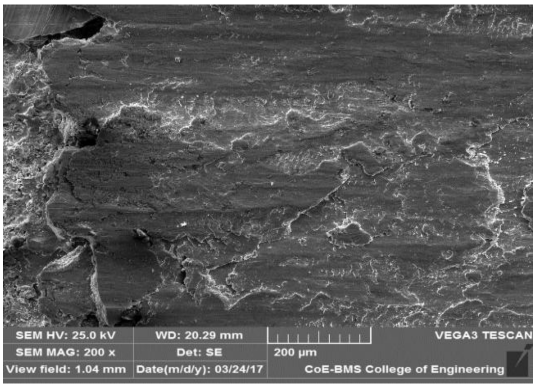
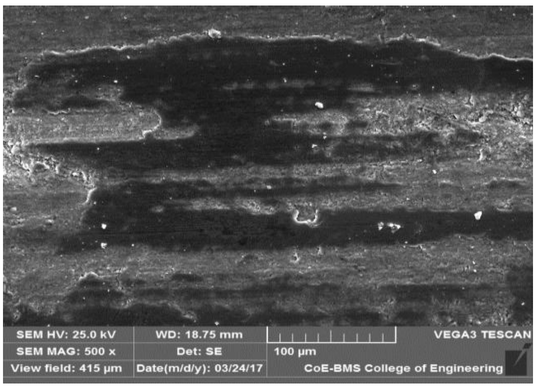


Fig.9: Micrograph of zinc coated pin surfaces at a magnification of 200x (a) 100 microns; (b) 200 microns; (c) 300 microns.

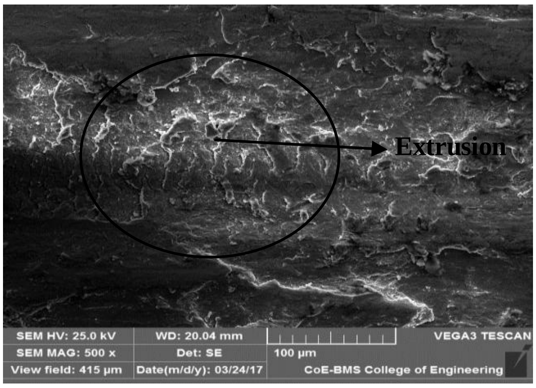
Micrograph of Fig.9a, 9b and 9c are correspond to respectively zinc coating thickness of 100 microns, 200 microns and 300 microns at a magnification of 200x.

The extent of damages in micrograph of Fig.9a is less severe compared to micrograph in Fig.9b and 9c. Micrograph in Fig.9c shows extrusion of wear debris which are absent in both micrograph of Fig.9a and 9b. This difference in micrograph of worn surfaces could be attributed to the observed dependency of co-efficient of friction and thickness.

(a)



(b)



(c)

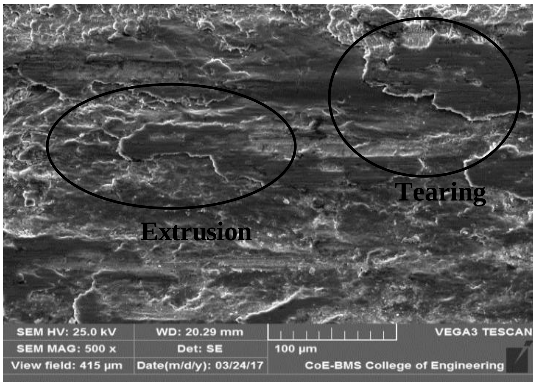


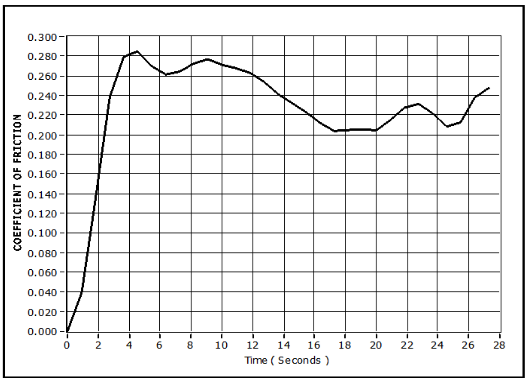
Fig.10: Micrograph of zinc coated pin surfaces at a magnification of 500x (a) 100 microns; (b) 200 microns; (c) 300 microns.

Worn surfaces for better clarity, were studied in Scanning electron micrograph at a higher magnification of 500x. Fig.10 shows the micrograph of worn zinc coated pin surfaces. Micrograph of Fig.10a, 10b and 10c are correspond to respectively zinc coating thickness of 100 microns, 200 microns and 300 microns at a magnification of 500x. The morphology more clearly brings out the extent of non-uniform displacement. The extent of extrusion and tearing of extruded wear particles are clearly seen in micrograph of Fig.10c. Smaller extent of extrusion is seen in micrograph of Fig.10b.

C. Aluminium coating

Aluminium coating thickness of 100 microns, 200 microns and 300 microns were coated on mild steel pins. Frictional force and normal forces were monitored during sliding experiment. The co-efficient of friction was estimated using monitored frictional force and normal force. The typical plots of co-efficient of friction versus sliding time are shown in Fig.11.

(a)



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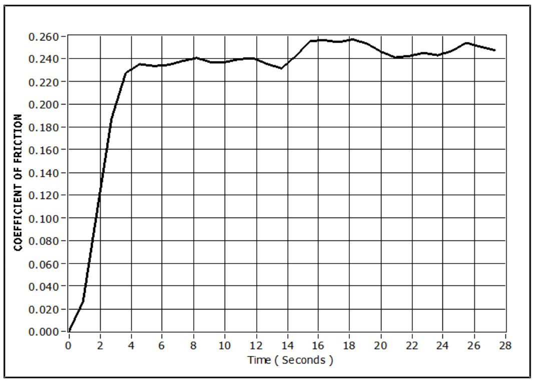

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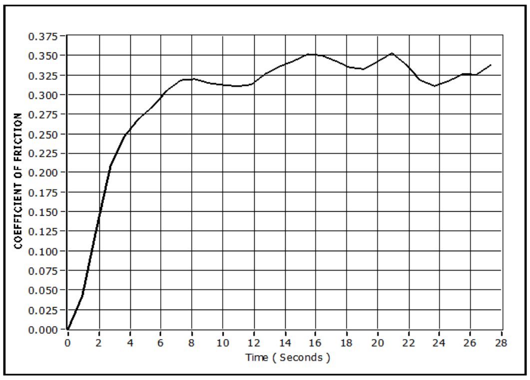


Fig.11: Dependency of co-efficient of friction with respect to sliding time for different coating thickness of aluminium (a) 100 microns; (b) 200 microns; (c) 300 microns.

Fig.11a shows the dependency of co-efficient of friction with sliding time for aluminium coating thickness of 100 microns. The co-efficient of friction increases from nil to approximately 0.28 when pin was slid from rest to over a time of 5 seconds. The co-efficient of friction there apart decreased from 0.28 to 0.20 when pin was slid over further slid over a period which ranges from 5 seconds to 17 seconds. The co-efficient of friction stabilized with magnitude 0.24 after approximately 17 seconds.

Fig.11b shows the dependency of co-efficient of friction with sliding time for aluminium coating thickness of 200 microns. The co-efficient of friction increases from nil to approximately 0.23 when pin was slid from rest to over a time of 5 seconds. The co-efficient of friction stabilized with magnitude 0.24 after approximately 5 seconds.

Fig.11c shows the dependency of co-efficient of friction with sliding time for aluminium coating thickness of 300 microns. The co-efficient of friction increases from nil to approximately 0.32 when pin was slid from rest to over a time of 7 seconds. The co-efficient of friction was stable up to 12 seconds then it stabilized with magnitude 0.33 after approximately 12 seconds.

The co-efficient of friction data from Fig.11 were used for estimating average co-efficient of friction. The estimated average co-efficient of friction for different coating thickness of aluminium are tabulated in Table IV.

Table IV: Average co-efficient of friction for different coating thickness of aluminium.

Sl No.	Coating thickness in microns	Co-efficient of friction
1	100	0.24
2	200	0.24
3	300	0.28

The data in Table IV is used for plotting the graph showing the dependency of co-efficient of friction on coating thickness for aluminium coating when slid against En 31 hardened steel.

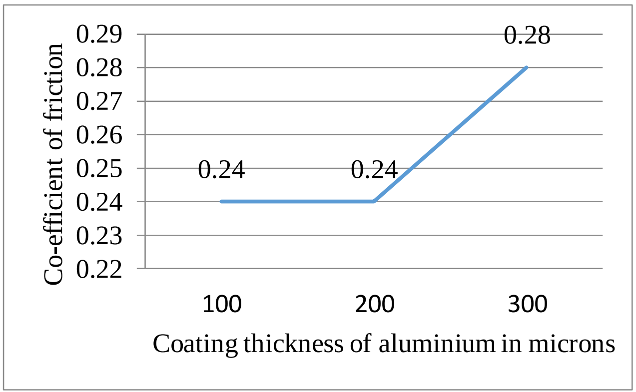
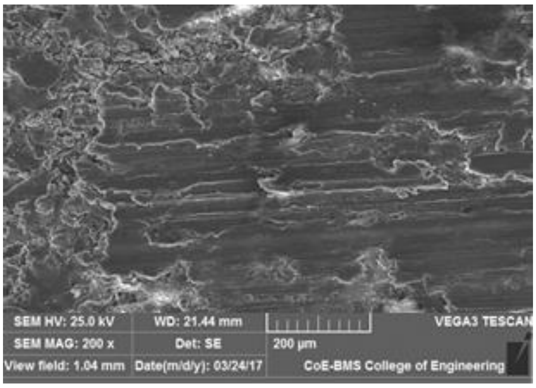


Fig.12: Co-efficient of friction against coating thickness of aluminium.

Fig.12 shows the dependency of coefficient of friction with coating thickness of aluminium. The coefficient of friction was found to be 0.24 for aluminium coating thickness of 100 microns and 200 microns aluminium coating thickness was increased to 300 microns.

Scanning electron micrographic studies have been carried out on worn aluminium coated pin surfaces for understanding the dependency of coefficient of friction with different coating thickness of aluminium as shown in Fig.13.

(a)



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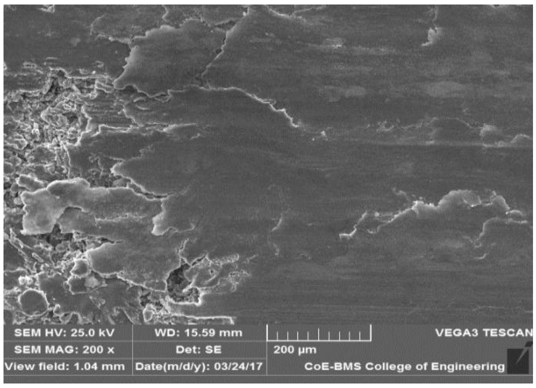


(c)

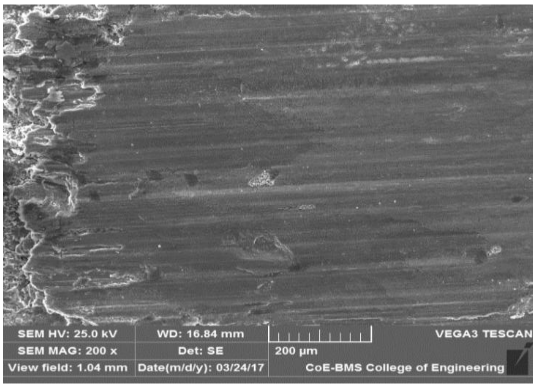


Fig.13: Micrograph of aluminium coated pin surfaces at a magnification of 200x **(**a) 100 microns; (b) 200 microns; (c) 300 microns.

Micrograph of Fig.13a, 13b and 13c are correspond to respectively aluminium coating thickness of 100 microns, 200 microns and 300 microns at a magnification of 200x. All the micrograph was taken at leading edge of pin. Micrograph of Fig.13a and 13b for aluminium coating of thickness 100microns and 200microns appears to be different from micrograph of figure 13c which corresponds to aluminium coating thickness of 300 microns. Micrograph of figure 13c appears to be more evenly exposed for wear compare to micrograph of Fig.13a and 13b.

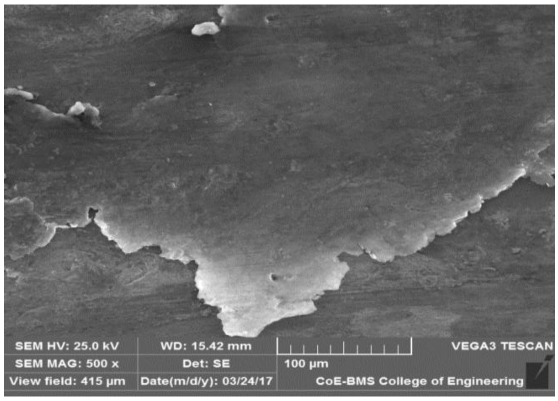


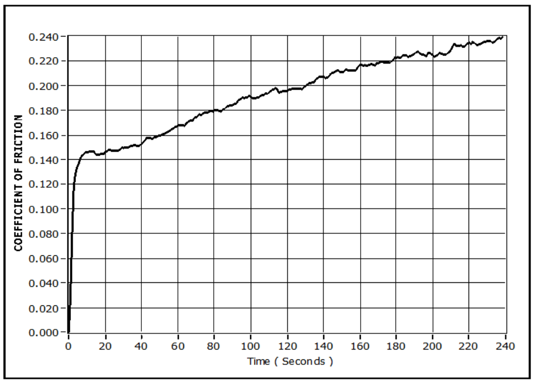
Fig.14: Micrograph of aluminium coated pin surfaces at a magnification of 500x.

Worn surfaces for better clarity, were studied in scanning electron micrograph at a higher magnification of 500x. The micrograph at higher magnification appears to be similar for all coating thickness and a typical micrograph at magnification of 500x for aluminium coating thickness of 200 microns is shown in Fig.14. The micrograph appears to be smooth.

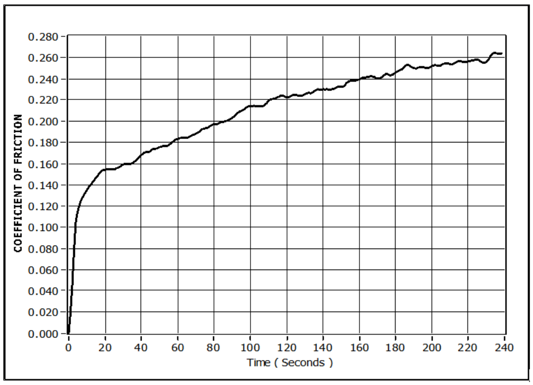
D. Molybdenum coating

Molybdenum coating thickness of 200 microns, 250 microns and 300 microns were coated on mild steel pins. Frictional force and normal forces were monitored during sliding experiment. The co-efficient of friction was estimated using monitored frictional force and normal force. The typical plots of co-efficient of friction versus sliding time are shown in Fig.15.

(a)



(b)



(c)

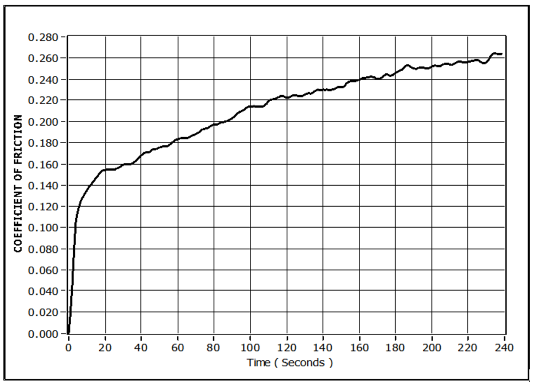


Fig.15: Dependency of co-efficient of friction with respect to sliding time for different coating thickness of molybdenum (a) 200 microns; (b) 250 microns; (c) 300 microns.

Fig.15a shows the dependency of co-efficient of friction with sliding time for molybdenum coating thickness of 200 microns. The co-efficient of friction steeply increases from nil to 0.15 when pin was slid from rest to over a time of 15 seconds. The increase in co-efficient of friction beyond 15 seconds was not as steep as in case of 0 to 15 seconds sliding.

Fig.15b shows the dependency of co-efficient of friction with sliding time for molybdenum coating thickness of 250 microns. The co-efficient of friction steeply increases from nil to 0.155 when the pin was slid over from rest to a time of 20 seconds. The increase in co-efficient of friction beyond 20 seconds was not as steep as in case of 0 to 20 seconds sliding.

Fig.15c shows the dependency of co-efficient of friction with sliding time for molybdenum coating thickness of 300 microns. The graph shows that the co-efficient of friction increases from nil to 0.18 when the pin was slid from rest to over a time of 20 seconds. The increase in co-efficient of friction beyond 20 seconds was not as steep as in case of 0 to 20 seconds sliding.

The co-efficient of friction data from Fig.15 were used for estimating average co-efficient of friction. The estimated average co-efficient of friction for different coating thickness of molybdenum are tabulated in Table V.

Table V: Average co-efficient of friction for different coating thickness of molybdenum.

Sl No.	Coating thickness in microns	Co-efficient of friction
1	100	0.20
2	200	0.22
3	300	0.25

The data in Table V is used for plotting the graph showing the dependency of co-efficient of friction on coating thickness for molybdenum coating when slid against En 31 hardened steel

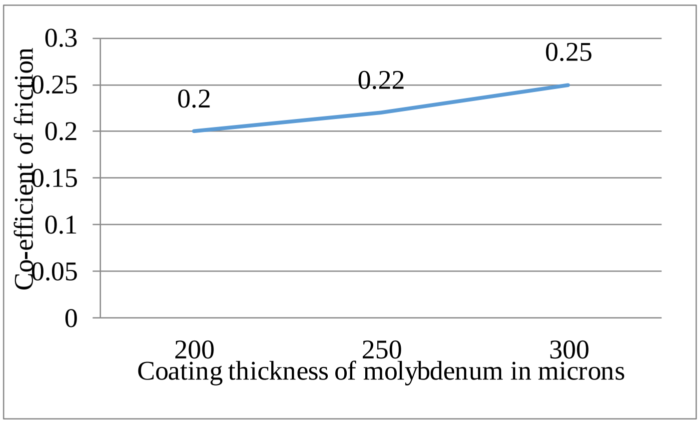


Fig.16: Co-efficient of friction against coating thickness of molybdenum.

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Fig.16 shows the dependency of coefficient of friction against coating thickness of molybdenum. The coefficient of friction was found to be 0.20, 0.22 and 0.25 respectively for molybdenum coating thickness of 200 microns, 250 microns and 300 microns. The coefficient of friction was found increase with increase in coating thickness of molybdenum.

Scanning electron micrographic studies have been carried out on worn molybdenum coated pin surfaces for understanding the dependency of coefficient of friction with different coating thickness of Molybdenum as shown in Fig.17.

(a)

(b)

(c)

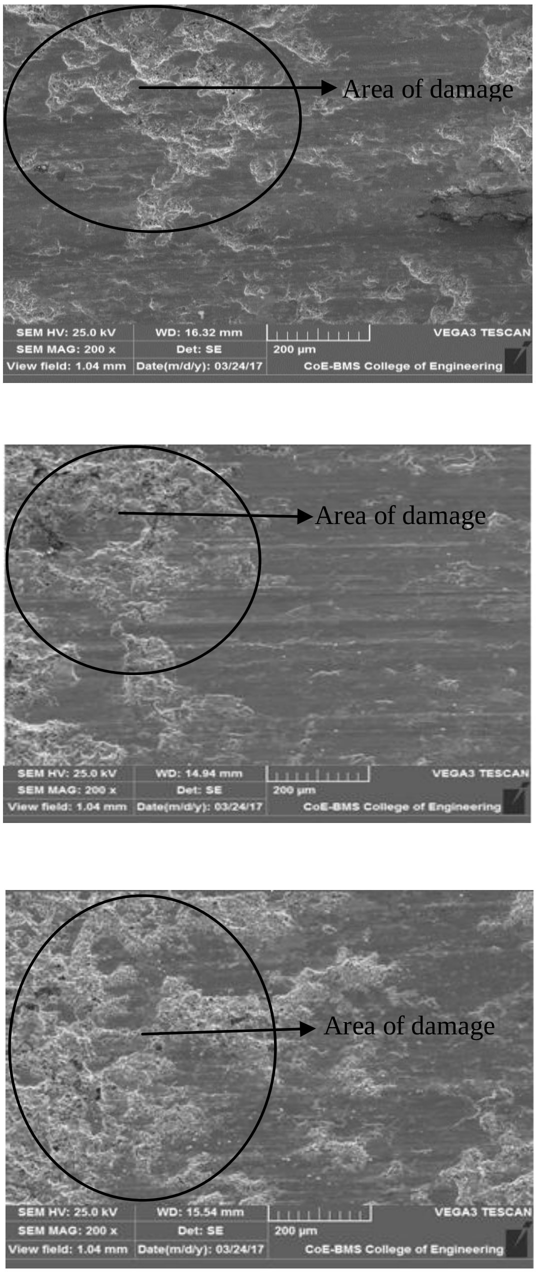

Fig.17: Micrograph of molybdenum coated pin surfaces at a magnification of 200x (a) 200 microns; (b) 250 microns; (c) 300 microns.

Micrograph of Fig.17a, 17b and 17c are correspond to respectively molybdenum coating thickness of 200 microns, 250 microns and 300 microns at a magnification of 200x. Micrograph shows the extent of damages with respect to increase in coating thickness. The degree of damages is found to increase with increase in coating thickness. The damage in micrograph of Fig.17a is less when compared to damages in micrograph of Fig.17b and 17c. The degree of damage in micrograph of figure 17b is compared to micrograph of Fig.17c is less.

(a)

(b)

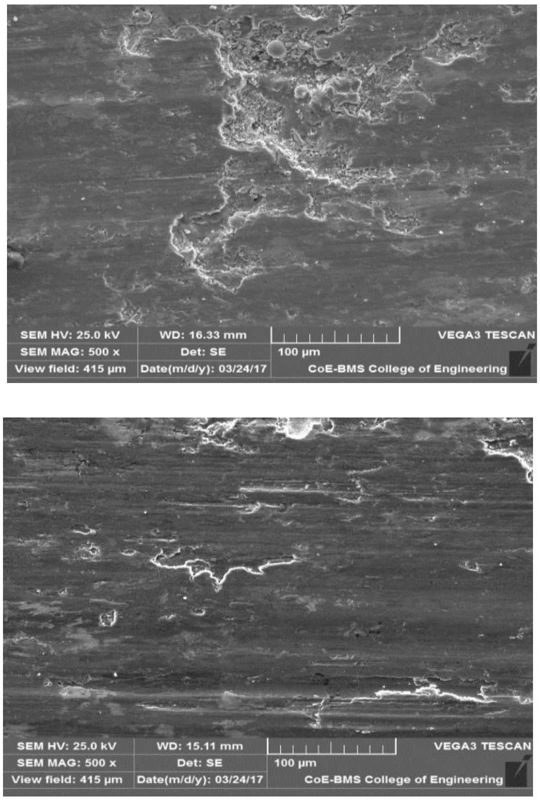

Fig.18: Micrograph of Molybdenum coated pin surfaces at a magnification of 500x (a) 200 microns; (b) 250 microns.

Worn surfaces for better clarity, were studied in Scanning electron micrograph at a higher magnification of 500x. Fig.18 shows the micrograph of worn molybdenum coated pin surfaces. Micrograph of Fig.18a and 18b are correspond to respective molybdenum coating thickness of 200 microns and 250 microns at a magnification of 500x. The morphology shows that there are not much differences in worn out surface features.

IV. CONCLUSIONS

A. Enamel coating:

- The coefficient of friction was found to increase with increase in enamel coating thickness upto 200 microns. The coefficient of friction was found to stabilize with further increase in enamel coating thickness.
- The extent of damage of coating thickness observed is in correlation with observed dependency of coefficient of friction with enamel coating thickness.

B. Zinc coating:

- The coefficient of friction was found monotonically increasing with increase in zinc coating thickness.
- The extent of damage of zinc coating thickness was found to be relatively less severe at lower zinc coating thickness. Phenomenon of tearing of coating and extrusion of wear debris features were observed at higher zinc coating thickness.

C. Aluminium coating:

- Not much variation in coefficient of friction was observed with increase in aluminium coating thickness upto 200 microns. The coefficient of friction was found to increase when aluminium coating thickness was more than 200 microns.
- The extent of damage of coating surface was found to be more with increase in coating thickness and is the reason for observed dependency of friction with coating thickness.

D. Molybdenum coating:

- The coefficient of friction was found monotonically increasing with increase in coating thickness.
- The extent of damage in coating thickness was found to increase with increase in coating thickness of molybdenum. The scanning electron micrograph features explains the dependency of coefficient of friction with increase in coating thickness.

In general, the coefficient of friction was found to increase with increase in coating thickness for different coating materials. The morphological features of damaged coating reveal the dependency of coefficient of friction with coating thickness.

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