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# Role of Velocity Discontinuity Imparted by Copper and Nickel Coatings of Different Thickness

**Salim Sharieff, S.Ranganatha**

***Abstract***: ***In mating pairs system, the pairs will have relative motion among themselves resulting in damage of contacting surfaces. During such relative motions friction and wear occurs. Extensive research has been carried out for identifying friction and wear effects. One of the important factors is found to be discontinuity in velocity at the interacting surfaces. This discontinuity in velocity was found to have a major role in affecting coefficient of friction and wear.In the present investigation to impart velocity discontinuity copper and nickel coatings of different thickness, were coated on mild steel pin. The copper coating was incorporated by thermal spray technique and nickel coating was carried by electroplating technique. Experiments have been conducted using pin on disc test rig with speed 500 rpm, load 30 newton and sliding time 30 seconds. The shear force was monitored in personal computer and coefficient of friction was estimated. Scanning electron micrograph (SEM) and Energy dispersive analysis X-ray (EDAX) was carried out. The coefficient of friction was found to be dependent on type of coating materials. Coefficient of friction was in the range of 0.51 to 0.52 for copper coating and 0.43 to 0.46 for nickel coating. The observed features in scanning electron micrograph attribute dependency of friction coefficient on coating thickness. The energy dispersive analysis X-ray study reveals no oxidation of copper, nickel and iron.***

***Keywords: Coatings, Friction, Wear, Velocity discontinuity.***

## I. INTRODUCTION

Researchers have carried out number of laboratory simulating experiments for elucidating the friction and wear phenomenon in a tribosystem. Kaleicheva and Karaguiozova conducted experiments for evaluating nickel coating on iron alloy. Experiments have been conducted according to Polish Standard PN-83/H-04302. The intensity of maximum Herztian contacts stress was found to be one of the factors for initiating coating failures [1]. Dewan and Assaduzzaman studied the wear and friction behaviour of copper and aluminium using pin on disc apparatus. Mild steel pin was slid against copper and aluminium disc. Different normal loads and sliding speeds were maintained during experiment. They found that in general coefficient of friction and wear rate of copper was found to be smaller compared to aluminium [2]. Vencl et al simulated erosion wear in the laboratory by conducting pin on disc experiments. The pin was coated with nickel and iron based coatings. The plasma arc welding, flame and electric arc spraying technique were used for coating. Nickel based coating exhibited better erosive wear compared to iron based coatings. The better performance of nickel based coating was attributed to different type and morphological features of reinforcing particles [3]. Krasmik and Schlattmann conducted experiment using ball on prism setup for evaluating brass and copper against steel. Dfferent loads, sliding velocities and contact points were employed in the experiment. In case of brass the friction coefficient was found to be less sensitive for all three variables. The copper showed the dependency of friction coefficient on sliding velocity and normal load [4]. Jothi et al made attempt for understanding the role of pretreatment Zn (zincate), Ni strike and absorbed hypophosphite on performance of electroless nickel-phosphorus coating. Experiments were conducted using pin on disc test rig. Pretreatment with Ni strike with combination of heat treatment resulted in improved frictional behaviour of nickel- phosphorus coating [5]. Lee et al tried to evaluate performance of Zn-Ni alloy coating with varying humidity levels. Test were conducted using pin on disc test rig. Better tribological performance was observed at elevated level of humidity. The better performance was attributed to formation of zinc oxide [6]. Ivanov et al studied the performance of vibrational MoS2 coating. Experiments were conducted using and MTU-1 universal frictional machine. They tried to evaluate the role of metal coating interface on tribological behaviour [7]. Rafael et al made attempt in evaluating role of CrN duplex PVD coating on pre-nitride tool steel. Commercial microscale abrasive wear testing device with the brand name KaloMAX NT II, was used. The results showed that the hardness of coating influence the frictional behaviour whereas adhesion of the coating did not influence the tribological behaviour [8]. Zambrano et al made attempt to evaluate the sliding wear materials of same hardness. Block on ring configuration was used for testing. The results showed that yield stress and microstructure of the pair have a role in tribosystem [9].

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* Correspondence Author
**Salim Sharieff***, Research Scholar, Department of Mechanical Engineering, Bangalore University and Assistant Professor, Department of Mechanical Engineering, HKBK College of Engineering, Bengaluru, India. Email:salim.sharieff08@gmail.com
**Dr.S.Ranganatha**, Professor, Department of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore University, Bengaluru, India. Email:rvasuran@gmail.com

Umanskyi et al conducted experiments for evaluating performance of NiAl based coating reinforced with borides. Pin on disc test rig was used for conducting the experiments. The wear performance was found to be better when Ti, Cr and Zn diborides are added to metallic coatings [10].

Norio et al tried to evaluate tribological behaviour of nickel free Co-Cr-Mo alloy in a simulated environment. The environment was found to influence the wear behaviour [11]. Blesman et al made an attempt to evaluate the quality of adhesion of coating. The sclerometry method was used to evaluating adhesion force. The author's found a good correlation between theoretical and experimental values [12]. Joy and Amar made attempt in evaluating performance of aluminium based journal bearings with and without lubrication. Pin on disc test rig apparatus was used for conducting the experiment. Authors evaluated the role of silicon, chromium and nickel which were used as alloying elements [13]. Gurcan and Baker made attempt in evaluating tribo behaviour of AA 6061 aluminium alloy and its composites. Test were conducted using pin on disc test rig. Composites with SiC particulate and Saffil composite was found to have better tribological performance [14]. Jianting et al conducted experiments for evaluating NiAl based materials. Pin on disc test rig was used for conducting the experiments. The results of improved tribological behaviour was attributed to the compacting self-lubricating film [15].

In the present investigation for obtaining different velocity discontinuity at the interface, copper and nickel coating have been given on pin surface.

## II. EXPERIMENTAL DETAILS

Mild steel pin was machined as per dimensions which are given in Fig.1 [16].

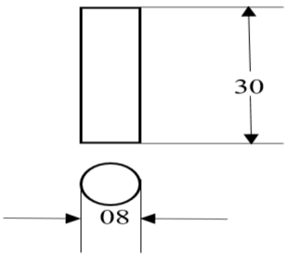



**Fig.1: Dimensions of the pin used in mm.**

Such machined pins have been coated with copper and nickel coatings of thickness of 100 microns, 200 microns and 300 microns. The copper coating was incorporated by thermal spray technique and nickel coating was carried by electroplating technique.

Test rig used is Pin on disk and shown in Fig.2 [16].


**Fig.2: Pin holder and disk.**

The test has been conducted and the test variables 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. | Copper | 30 | 30 | 500 |
| 2. | Copper | 30 | 30 | 500 |
| 3. | Copper | 30 | 30 | 500 |
| 4. | Nickel | 30 | 30 | 500 |
| 5. | Nickel | 30 | 30 | 500 |
| 6. | Nickel | 30 | 30 | 500 |

Experiments were conducted according to ASTM G99. The frictional force and co-efficient of friction were monitored using personal computer.

## III. REULTS AND DISCUSSION

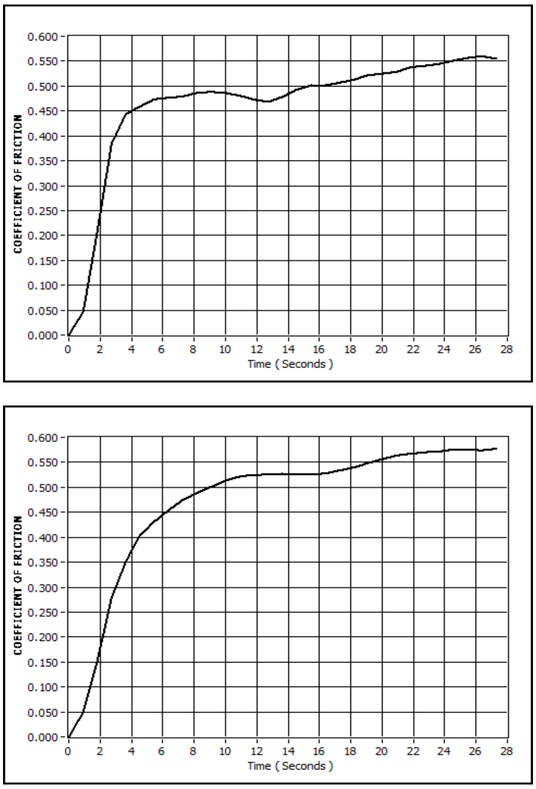
Mild steel pin coated with copper and nickel for obtaining different velocity discontinuity at the interface were slid against En 31 hardened steel disc according to ASTM procedure using pin on disc test rig.

### A. Copper coating

Coating thickness of 100 microns, 200 microns and 300 microns of pure copper were coated on mild steel pin. The coated steel pin was slid on pin on disc test rig. The shear force was monitored using personal computer. The co-efficient of friction was estimated using monitored shear force and load. The typical plots of showing the dependency of co-efficient of friction with respect to sliding time are shown in Fig.3.

(a)

(b)

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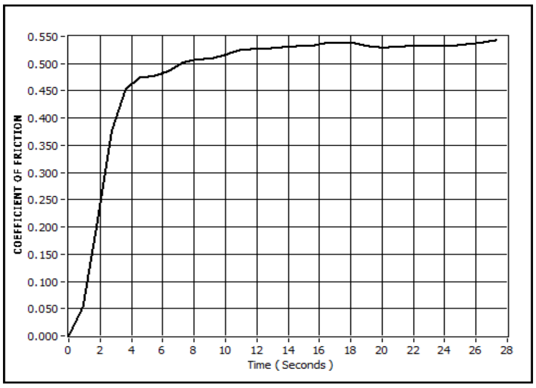



**Fig.3: Plots of co-efficient of friction with respect to sliding time for copper coating thickness of (a) 100 microns; (b) 200 microns; (c) 300 microns.**

The dependency of co-efficient of friction on sliding time for 100 microns coating thickness of copper is shown in Fig.3a. The figure shows that friction co-efficient increased monotonically to approximately 0.45 from the beginning to sliding time of 4 seconds. The friction co-efficient after 4 seconds and during the rest of the sliding was found to be approximately 0.51 with small deviations.

The dependency of co-efficient of friction on sliding time for 200 microns coating thickness of copper is shown in Fig.3b. The figure shows that friction co-efficient increased monotonically to approximately 0.5 from the beginning to sliding time of 8 seconds. The friction co-efficient after 8 seconds and during the rest of the sliding was found to be approximately 0.52 with small deviations.

The dependency of co-efficient of friction on sliding time for 300 microns coating thickness of copper is shown in Fig.3c. The figure shows that friction co-efficient increased monotonically to approximately 0.45 from the beginning to sliding time of 4 seconds. The friction co-efficient after 4 seconds and during the rest of the sliding was found to be approximately 0.52 with small deviations.

The data from Fig.3, excluding the co-efficient of friction data during initial monotonic increase, are used for establishing average co-efficient of friction. Such estimated average co-efficient of friction are tabulated in Table II.

**Table II. Dependency of average co-efficient of friction on coating thickness of copper.**

| Sl No. | Coating thickness in microns | Co-efficient of friction |
|---|---|---|
| 1 | 100 | 0.51 |
| 2 | 200 | 0.52 |
| 3 | 300 | 0.52 |

The average co-efficient of friction shown in Table II are plotted and shown in Fig.4.

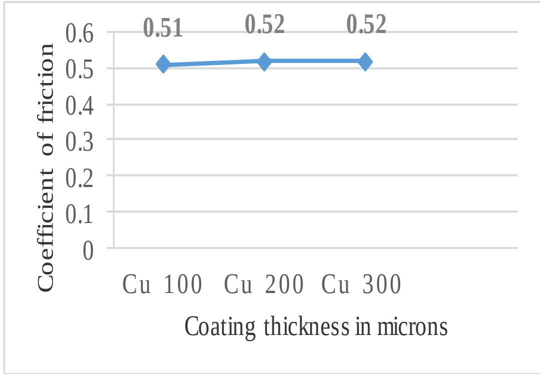


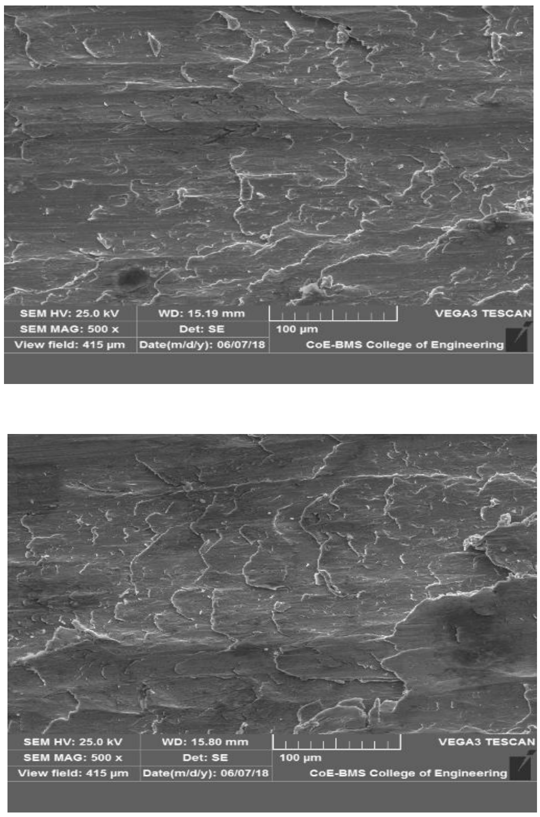

**Fig.4: Average co-efficient of friction for different coating thickness of copper.**

Fig.4 shows the average co-efficient of friction for different coating thickness of copper. It is found from the plot that the co-efficient of friction was found to be 0.51, 0.52 and 0.52 respectively for copper coating thickness of 100 microns, 200 microns and 300 microns. The result indicates as coating thickness change from 100 microns to 200 microns and 300 microns, the average co-efficient of friction change from 0.51 to 0.52.

Scanning electron micrographic studies for understanding the dependency of co-efficient of friction with different coating thickness of copper have been carried out on worn out pin surface as shown in Fig.5.

(a)

(b)



(c)

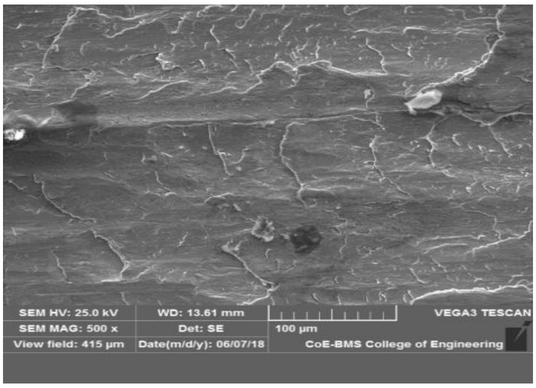


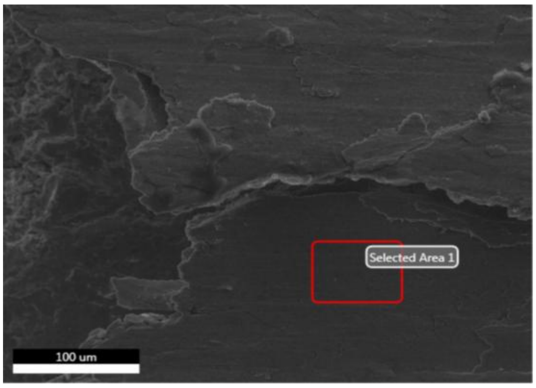

**Fig.5: Micrograph of worn out pin surfaces for different copper coating thickness at a magnification of 500x (a) 100 microns; (b) 200 microns; (c) 300 microns.**

Micrograph in Fig.5a, 5b and 5c shows the worn out pin surfaces for different copper coating thickness at a magnification of 500x.

Micrographs in Fig.5 shows damaged copper coatings on mild steel pin. All the three micrographs show damaged patches of copper coatings. The damaged patches of Fig.5a appears to be more refined when compared to micrographs in Fig.5b and 5c. The average area of patches in Fig.5b and 5c appears to be bigger when compared to average area of patches in Fig.5a. The substrate iron pin surface in any studied pin is not exposed. The morphology in Fig.5a shows the more of adhesive features. The morphology scanning electron micrograph of Fig.5b and Fig.5c appears to be almost similar. These features of Scanning electron micrograph explain the observed dependency of coefficient of friction with coating thickness of copper.

Energy dispersive analysis X-ray (EDAX) studies have been carried out for coating of 100 microns. 100 microns coating thickness was chosen since coefficient of friction appeared to be independent of coating thickness. The substrate iron pin surface was not exposed in all coated pins. Oxidation of either copper or iron was not found. Energy dispersive analysis X-ray study was carried out at four different selected areas of the 100 microns coating pin. Typical Energy dispersive analysis X-ray micrograph of selected area 1 is shown in the Fig.6.

(a)




(b)

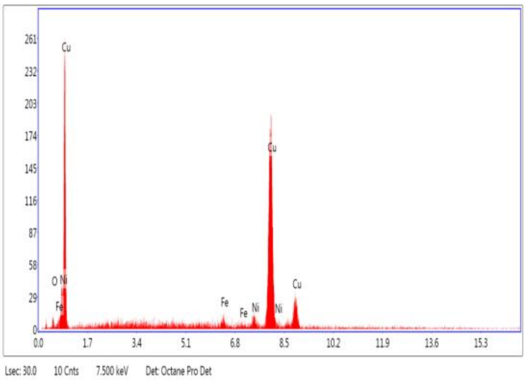



**Fig.6: (a) and (b) are EDAX micrograph of selected area 1 of copper coated pin.**

The weight percentage of only copper, iron and oxygen at four different selected areas of the pin is shown in Table III.

Table III: The weight % of only copper, iron and oxygen at four different selected areas of the pin.

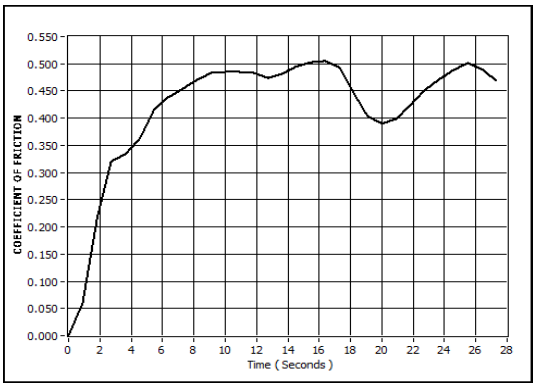
| **Area** | **Elements weight % at different areas of the pin** | | |
|---|---|---|---|
| | **Copper** | **Iron** | **Oxygen** |
| 1 | 94.90 | 0.87 | 1.83 |
| 2 | 94.34 | 1.42 | 2.29 |
| 3 | 95.67 | 1.46 | 1.61 |
| 4 | 95.02 | 0.86 | 3.22 |

Copper was found to be in the range of 95%, iron was found to be in the range of 1.5% and oxygen was found to be in the range of 3.22.

**B. Nickel coating**

Coating thickness of 100 microns, 200 microns and 300 microns of pure nickel were coated on mild steel pin. The coated steel pin was slid on pin on disc test rig. The shear force was monitored using personal computer. The co-efficient of friction was estimated using monitored shear force and load. The typical plots of showing the dependency of co-efficient of friction with respect to sliding time are shown in Fig.7.

(a)



(b)

(c)

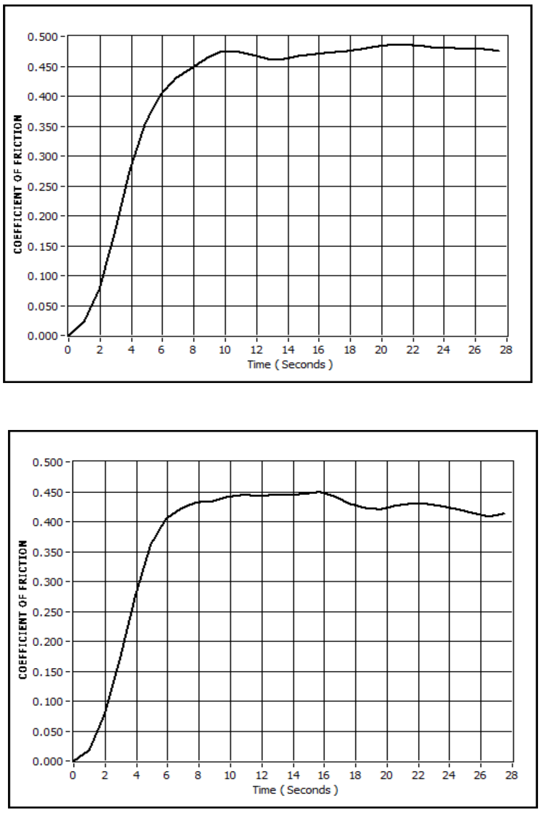



**Fig.7: Plots of co-efficient of friction with respect to sliding time for nickel coating thickness of (a) 100 microns; (b) 200 microns; (c) 300 microns.**

The dependency of co-efficient of friction on sliding time for 100 microns coating thickness of nickel is shown in Fig.7a. The figure shows that friction co-efficient increased monotonically to approximately 0.4 from the beginning to sliding time of 6 seconds. The friction co-efficient after 6 seconds and during the rest of the sliding was found to be approximately 0.46 with small deviations.

The dependency of co-efficient of friction on sliding time for 200 microns coating thickness of nickel is shown in Fig.7b. The figure shows that friction co-efficient increased monotonically to approximately 0.45 from the beginning to sliding time of 8 seconds. The friction co-efficient after 8 seconds and during the rest of the sliding was found to be approximately 0.46 with small deviations.

The dependency of co-efficient of friction on sliding time for 300 microns coating thickness of nickel is shown in Fig.7c. The figure shows that friction co-efficient increased monotonically to approximately 0.4 from the beginning to sliding time of 6 seconds. The friction co-efficient after 6 seconds and during the rest of the sliding was found to be approximately 0.43 with small deviations.

The data from Fig.7, excluding the co-efficient of friction data during initial monotonic increase, are used for establishing average co-efficient of friction. Such estimated average co-efficient of friction are tabulated in Table IV.

**Table IV: Dependency of average co-efficient of friction on coating thickness of nickel.**

| Sl No. | Coating thickness in microns | Co-efficient of friction |
|---|---|---|
| 1 | 100 | 0.46 |
| 2 | 200 | 0.46 |
| 3 | 300 | 0.43 |

The average co-efficient of friction shown in Table IV are plotted and shown in Fig.8

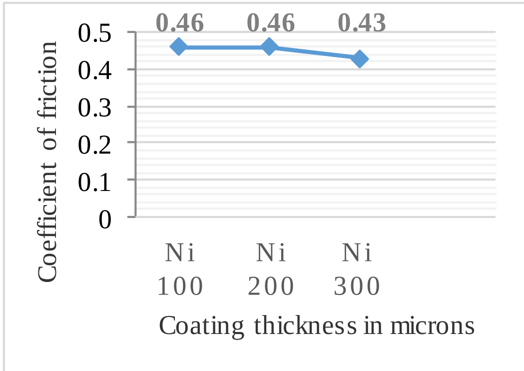
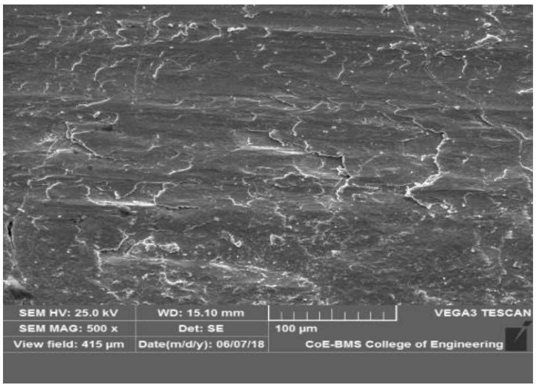



**Fig.8: Average co-efficient of friction for different coating thickness of nickel.**

Fig.8 shows the average co-efficient of friction for different coating thickness of copper. It is found from the plot that the co-efficient of friction was found to be 0.46, 0.46 and 0.43 respectively for nickel coating thickness of 100 microns, 200 microns and 300 microns. The co-efficient of friction was found to be same for coating thickness of 100 microns and 200 microns. However, there was a marginal decrease in co-efficient of friction to a value of 0.43 when nickel coating thickness was 300 microns.

Scanning electron micrographic studies for understanding the dependency of co-efficient of friction with different coating thickness of nickel have been carried out on worn out pin surface as shown in Fig.9.

(a)



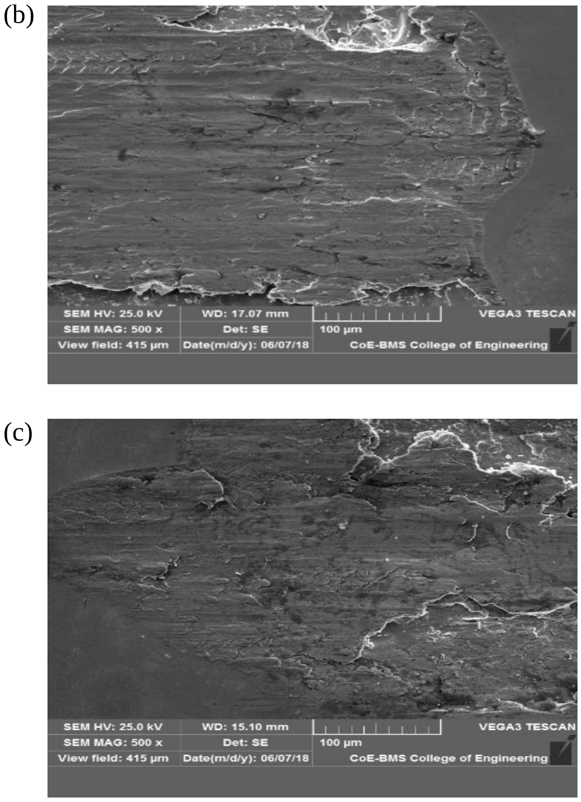



**Fig.9: Micrograph of worn out pin surfaces for different nickel coating thickness at a magnification of 500x (a) 100 microns; (b) 200 microns; (c) 300 microns.**

Micrograph in Fig.9a, 9b and 9c shows the worn out pin surfaces for different nickel coating thickness at a magnification of 500x.

Micrograph in Fig.9a shows the features of damaged nickel coating containing more patches of damaged area when compared to micrograph shown in Fig.9b and 9c. Micrograph in Fig.9b shows the deformed surface with less number of patches compared to micrograph in Fig.9a. Except these deviations in features micrograph in Fig.9a and 9b appears to be similar. Micrograph in Fig.9c shows the surface with more smoothness when compared to micrograph in Fig.9a and 9b. Tendency of adhesion features are not observed in micrograph in Fig.9c. Adhesion tendency features are not observed in micrograph Fig.9c. These variations in features of the micrograph in Fig.9a, 9b and 9c attribute the observed dependency of coefficient of friction on coating thickness.

Further Energy dispersive analysis X-ray (EDAX) studies was carried out for finding any interaction with oxygen of the environment on pin surface which was coated with 100 microns. Energy dispersive analysis X-ray analysis was carried out at four different selected areas of the pin. Typical Energy dispersive analysis X-ray micrograph of selected area 1 is shown in the Fig.10.

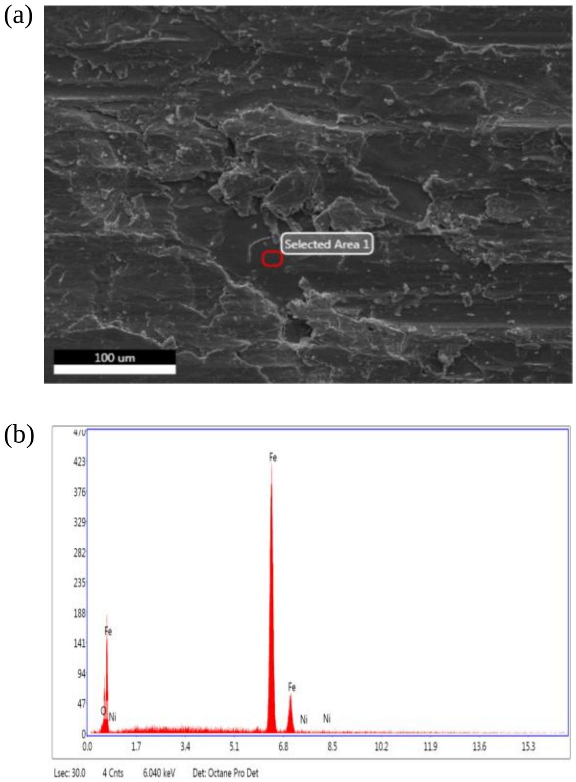



**Fig.10: (a) and (b) are EDAX micrograph of selected area 1 of nickel coated pin.**

The weight percentage of nickel, iron and oxygen at four different selected areas of the pin is shown in Table V.

**Table V: The weight % of nickel, iron and oxygen at four different selected areas of the pin.**

| Area | Elements weight % at different areas of the pin | | |
|---|---|---|---|
| | Nickel | iron | Oxygen |
| 1 | 0.92 | 97.34 | 1.74 |
| 2 | 74.47 | 24.56 | 0.96 |
| 3 | 88.21 | 8.96 | 2.83 |
| 4 | 88.34 | 9.08 | 2.58 |

The weight percentage of nickel was found to be 74.47%, 88.21% and 88.21% at three different selected areas of the pin, at these three areas weight percentage of iron was found to be 24.56%, 8.96 %and 9.08%. At selected area 1 weight percentage of nickel was found to be 0.92% and iron was 97.34%.

Energy dispersive analysis X-ray studies reveals that in all selected areas the oxygen was found to be less than 3% indicating that there was no sufficient oxygen for oxidation of nickel and iron.

## IV. CONCLUSION

1) The coefficient of friction was found to be influenced by type of coating material.
2) There appears to be a correlation between damaged coating surface and observed variation in coefficient of friction.

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3) The coefficient of friction was found to be not much dependent in the range coating thickness studied in the pin.
4) Oxidation of either coating material or mild steel was not observed.


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## AUTHORS PROFILE

**Salim Sharieff**, Research Scholar, Department of Mechanical Engineering, Bangalore University and Assistant Professor, Department of Mechanical Engineering, HKBK College of Engineering, Bengaluru, India. Associate member of Institute of Engineers (India)-AM1786235

**Dr.S.Ranganatha**, Professor, Department of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore University, Bengaluru, India.