International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-2 Issue-4, September 2013

Effect of Soft Material Hardness and Hard Material Surface Morphology on Friction and Transfer Layer Formation; Dry Condition

M Basavaraju, S Ranganatha

Abstract - The morphological features of the surface in both micro and macro levels are important factors governing the tribological behavior of the contacting surfaces. Surface hardness is also an important factor which governs the friction and wear behaviors of the contacting surfaces. Surface morphology of a tool is an important factor as it primarily controls the tribological behavior at the interface which in turn controls the surface finish of products. In the present investigation a pin-on-plate sliding tester was used to identify the effect of surface morphology and hardness on co-efficient of friction and transfer layer which characterizes the tribological behavior. The morphology of mild steel (EN8) plate surfaces were modified by employing three different surface modification methods like grinding (silicon carbide wheel polishing), shot blasting and electric discharge machining methods. Surface roughness parameters which characterize the morphology of the steel plates were measured using a three dimensional optical profilometer. Role of hardness is studied by employing lead, copper and Aluminum (Al6082) pins which were slid against steel plates. Experiments were conducted for plate inclination angles of 1, 1.5,2 and 2.5 degrees. Normal load was varied from 1 to 150N during the tests. Experiments were conducted under dry condition in ambient environment. Scanning electron microscope was used to study the formation of transfer layer on plate and pin surfaces. It was observed that the co-efficient of friction and transfer layer formation were found to depend on the surface morphology of the harder surface. The quantum of transfer layer formation on the surfaces is found to increase with increase in surface roughness.

Keywords: Friction, co-efficient of friction, surface morphology and transfer layer formation.

I. INTRODUCTION

The roughness theory assumed that the frictional force is equal to the force required to climb up the asperity of slope θ and the co-efficient of friction was described as a + function of tan (θ). However, it is clear that asperities undergo deformation due to the sliding action rather than simply sliding over each other. Archard [1] studied the influence of surface roughness on friction behavior of metals and non-metals. The author [1] noticed that effect of surface roughness on friction is largest at linear loads. From the experimental observations, it was found that friction co-efficient increases with surface roughness for hard materials and decreases with surface roughness for soft materials. Nellemann et al. [2] investigated the effect of different surface topography geometries by varying asperity angles and concluded that normal pressure and bulk modulus have great influence on the real area of contact, whereas the asperity slope and friction factor are of minor importance.

Whitehead [3] studied the effect of normal load on friction co-efficient for copper sliding against copper in air. The author concluded that copper shows lower friction at low loads as a result of oxide film formation that effectively separates the two metal surfaces, and exhibits high friction at high loads due to break down of the oxide film.

Bowden and Young [4] performed experiments to observe the effect of sliding speed on frictional response of copper. From their experiments, they observed very low friction co-efficient in copper at high sliding speeds. They explained that formation of a thin molten film reduces the friction co-efficient. This thin molten film acts as lubricant between sliding surfaces. Endo and Goto [5] showed that the frictional force between steel surfaces is much higher in argon atmosphere than in ambient conditions. Tsuya [6] investigated the friction of copper in vacuum and air. The author [6] found that the values of the friction co-efficient in vacuum were about 10 times higher than values measured in air. Hiratsuka et al. [7] studied the factors influencing friction and wear between metals and oxides from wear tests on different kinds of pure metals (silver, platinum, copper, magnesium, iron, titanium, aluminium). They concluded that the friction and wear depends on the oxidation activity of the metals, atmosphere oxygen and relative shear strength of the metal-oxide interface. Staph [8] studied the effect of surface texture and surface roughness on scuffing using caterpillar disc tester. Kaura [9] studied effect of surface texture on friction mechanism using a universal testing machine. The results showed that the behavior of surface and the friction during sliding depends on the degree of roughness. Menezes[10] studied the effect of directionality of surface ground marks on friction and transfer layer formation when Al-Mg alloy pins slid on steel plate of different surface roughness and author concluded that both Co-efficient of friction and transfer layer formation depend on ground angle.

Adhesive or abrasive mode of contact, primarily depends on the relative hardness and morphology of surface, is believed to be the reason for formation of transfer layer. The literature emphasis the importance of presence of a soft layer called transfer layer in characterizing both frictional forces and surface finish. The formation of transfer layer is found to be the important parameter which characterizes the behavior of interfacing surfaces. The parameters like the operating temperature, relative velocity between the surfaces, the harder surface topography , the type of sliding pairs and metallurgical affinity of the surfaces do influence the morphology of transfer layer which in turn characterizes the frictional behavior in case of mechanical machinery and surface finish and tolerances in case of manufacturing processes.

Manuscript received on September 3, 2013

Mr.M Basavaraju, Selection grade lecturer, Department of mechanical engineering, Government polytechnic, Channasandra, Bangalore, India.

Dr.S Ranganatha, Professor, Department of mechanical engineering, University Visveswaraya College of Engineering, Bangalore, India.

In the present study an attempt is made to understand the formation of transfer layer when parameters like surface topography of harder material and hardness of the soft material are varied.

II. EXPERIMENTAL PROCEDURE

Soft materials like Lead, Copper and aluminium (Al 6082) compared to harder mild steel (080M40 or EN8) are chosen as pin materials and EN8 is chosen as hard plate material in sliding experiment. Pins of dimensions 3mm diameter, 10mm length and 1.5mm nose radius were slid against mild steel plates. The dimensions of pin are shown in figure.1. The EN8 flat is machined accurately to dimensions as shown in fig 2. All dimensions are in mm.

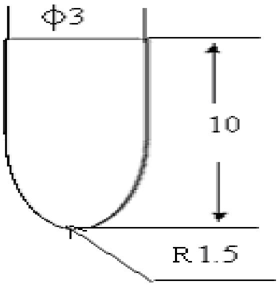


Fig. 1: Dimensions of pin

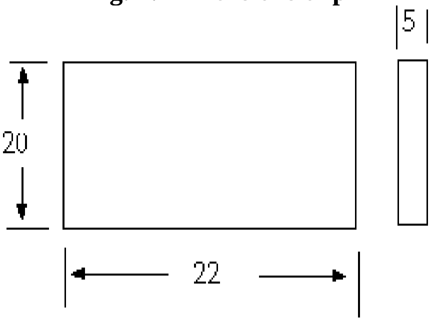


Fig. 2: Dimensions of Mild Steel (EN8) Plate

The EN8 flat surfaces were modified by using different methods like grinding (Silicon Carbide wheel polishing), sand blasting and electric discharge machining (EDM). The surface characteristics of the modified surfaces were studied using three dimensional optical profilometer. The average three dimensional surface roughness parameter Ra was measured. The typical three dimensional surface profile of the flat is shown in Figure.3.

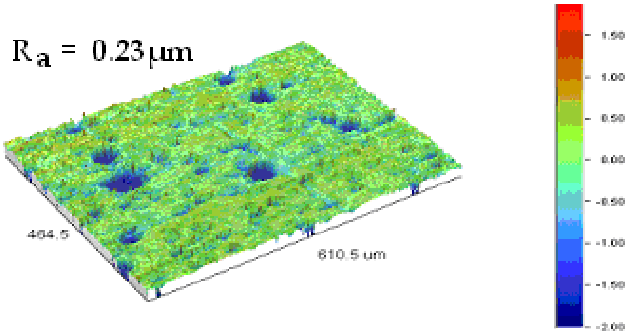


Fig. 3(a): The three dimensional view of ground (SiC wheel polished) plate surface.

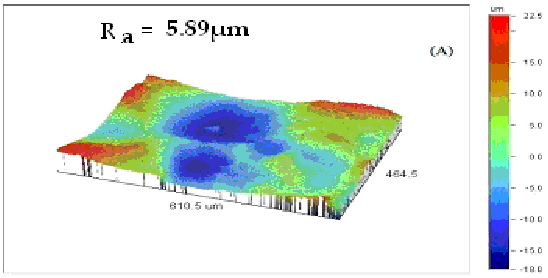


Fig. 3(b): The three dimensional view of shot blast plate surface.

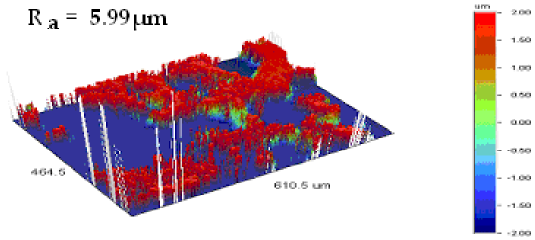


Fig. 3(c): The three dimensional view of EDM plate surface.

The average surface roughness value Ra of ground (Silicon Carbide wheel polished), sand blast and electric discharge machined (EDM) surfaces were respectively found to be 0.23μm, 5.89μm and 5.99μm. The Ra of ground (Silicon Carbide wheel polished) surface was minimum and Ra of Electric discharge machined surface was maximum. All the three surfaces were found to be peak dominated.

The pins were electro polished to remove any work-hardened layers that might have formed. Before each experiment the pins and steel plates were thoroughly rinsed with an aqueous soap solution. This was followed by cleaning the pins and plates with acetone in an ultrasonic cleaner.

The experiments were conducted using an inclined pin-on- plate sliding tester also called an inclined Scratch tester. It was also used to find the effect of load on the co-efficient of friction. A schematic diagram of pin and inclined plate is shown in figure 4.

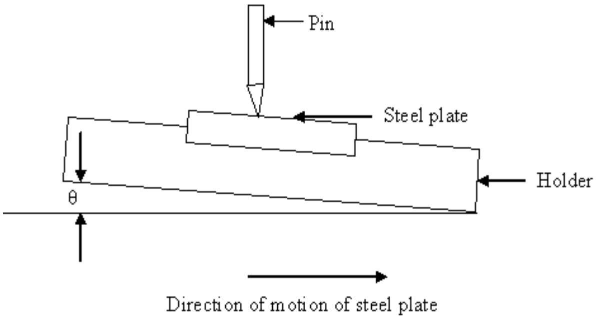


Fig. 4: Schematic diagram of Pin on Plate with Inclined steel plate.

The cleaned pins were slid at a velocity of 2mm/Sec against the cleaned EN8 steel plates from lower end to the higher end of the inclined surface for a sliding length of approximately 10 mm. The normal force and shear forces were continuously monitored using a computerized data acquisition system. The normal load was varied from 1-150N during the test.

The co-efficient of friction μ, which is the ratio of the shear force (T) to the normal force (N), was calculated from the recorded forces using the formula

$$\mu = \frac{T}{N} = \frac{F_T \cos\theta - F_N \sin\theta}{F_T \sin\theta + F_N \cos\theta}$$

Experiments were conducted for different parameters. The parameters were surface roughness (Ra), hardness of pin and plate inclination angle (θ). Pins used were lead, copper and aluminium. The surface roughness was characterized by Ra. The plate inclination angle was 1, 1.5,2 and 2.5 degrees.

For each parameter the sliding tests were conducted under dry conditions on each plate in ambient environment. For each inclination angle the test were conducted for different surface roughness values in dry condition. Tests were performed to obtain five parallel dry wear tracks on the same plate for each inclination angles. After experiment the pins and EN8 flat surface were studied in scanning electron microscope (SEM) to understand the origin of transfer layer and its relation with estimated friction co-efficient.

The experiments were conducted and a comparative study of co-efficient of friction against surface roughness and the formation of transfer layer was studied for lead, copper and aluminium pins slid against ground (silicon carbide polished), sand blast and electric discharge machined mild steel surfaces under dry conditions.

III. RESULTS AND DISCUSSIONS

The typical dependency of co-efficient of friction on sliding distance for ground (SiC polished), sand blast and EDM surfaces are respectively shown in figures 5, 6 and 7. The Y axis indicates co-efficient of friction values and X axis indicates the sliding distance in mm.

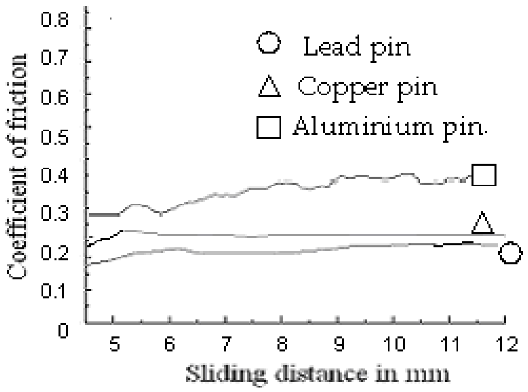


Fig. 5: Dependency of co-efficient of friction with sliding distance for ground (SiC polished) steel surface.

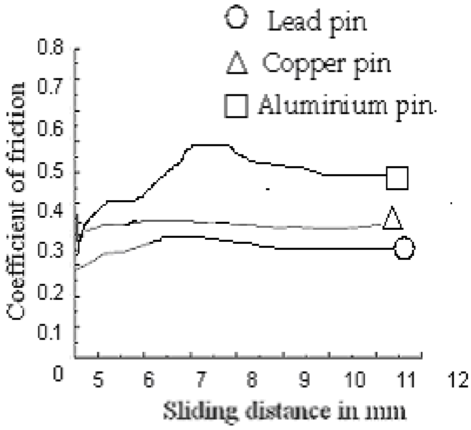


Fig. 6: Dependency of co-efficient of friction with sliding distance for shot blast steel surface

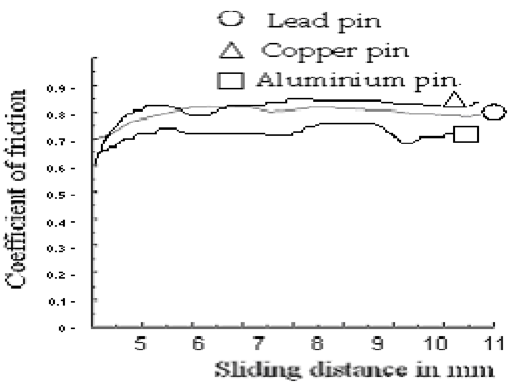


Fig.7: Dependency of co-efficient of friction with sliding distance for EDM surface

The graphs shown in figure.5, Figure.6 and Figure.7 shows the dependency of co-efficient of friction on sliding distance. The co-efficient of friction was found to be steady with sliding distance except a kink in figure. 6 for aluminium pin.

The co-efficient of friction for lead is found to be less when compared to copper and aluminium pins for ground (SiC wheel polished) and sand blast surfaces. In case of EDM surface the aluminium pin was found to have minimum co-efficient of friction instead of lead pin. Further the co-efficient of friction is found to increase with Ra of the surfaces. The steady state of sliding is found for all the sliding experiments and average frictional co-efficient is found from these experiments. These average co-efficient of friction are made use to understand the effect of plate inclination angle, hardness of pin and surface roughness of the flat surfaces.

The average co-efficient of friction was estimated and its dependency on plate inclination angle are shown in figures 8(a) (b)and (c), when lead, copper and aluminium pins were slid against ground (silicon carbide polished), shot blast and electric discharge machined steel surfaces.

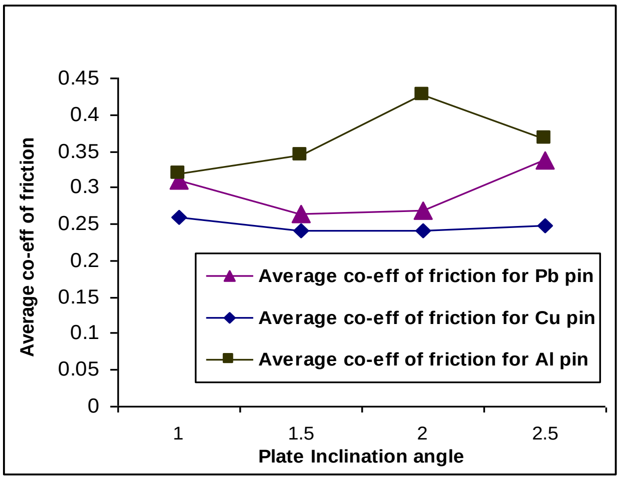


Fig. 8(a): The dependence of Average co-efficient of friction with plate inclination angle when Pb, Cu and Al pins slid on ground (SiC) steel surfaces.

The average co-efficient of friction except for aluminium at an angle of 2 degree, for different pin material shown in figure 8(a), was found not to vary much with plate inclination angle when slid on ground (SiC) steel surfaces.

The co-efficient of friction for aluminium pin at 2 degree inclination angle was found to be more compared to other inclination angle of surfaces.

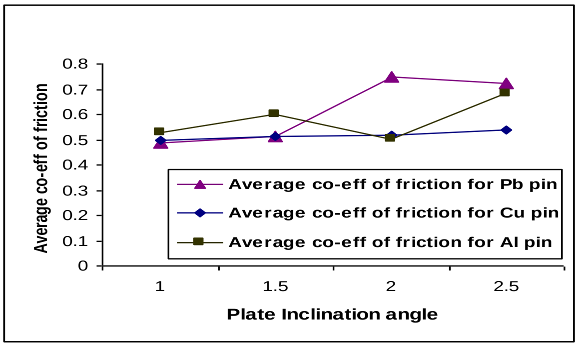


Fig. 8(b): The dependence of Average co-efficient of friction with plate inclination angle when Pb, Cu and Al pins slid on shot blast steel surfaces

The average co-efficient of friction in case of shot blast surfaces which is shown in figure 8(b),similar to ground (SiC) steel surfaces, was also found not to vary much with plate inclination angle except a small fluctuation in average co-efficient of friction value for lead pin at an inclination angle of 2 and 2.5 degrees.

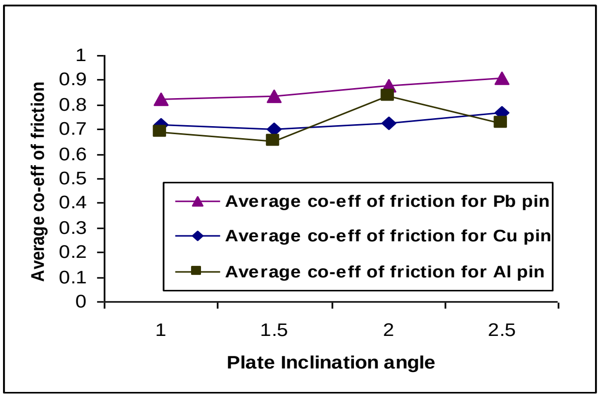


Fig. 8(c): The dependence of Average co-efficient of friction with plate inclination angle when Pb, Cu and Al pins slid on electric discharge machined steel surfaces.

The average co-efficient of friction in case of electric discharge machined steel surfaces, which is shown in figure 8(c),Similar to ground (SiC) steel surfaces, is also found not to vary much with plate inclination angle.

The average co-efficient of friction for lead, copper and Aluminium pins were plotted against the roughness parameter of the harder steel surface at various plate inclination angles. These plots are shown in figures 9(a), 9(b), 9(c) and 9(d).

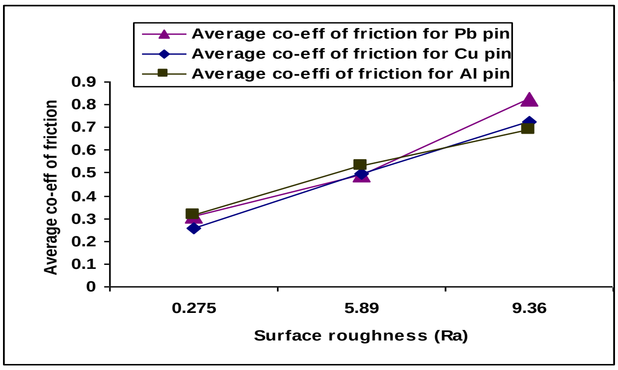


Fig. 9 (a): The variation of average co-efficient of friction with surface roughness (Ra) for Pb, Cu and Al pins slid on steel surfaces when θ=1 degree.

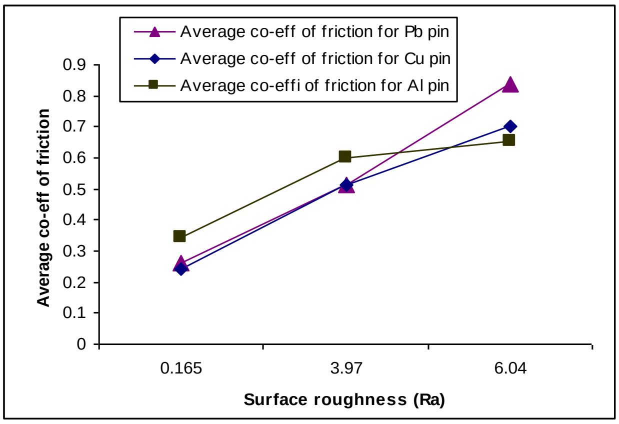


Fig. 9 (b): The variation of average co-efficient of friction with surface roughness (Ra) for Pb, Cu and Al pins slid on steel surfaces when θ= 1.5 degree

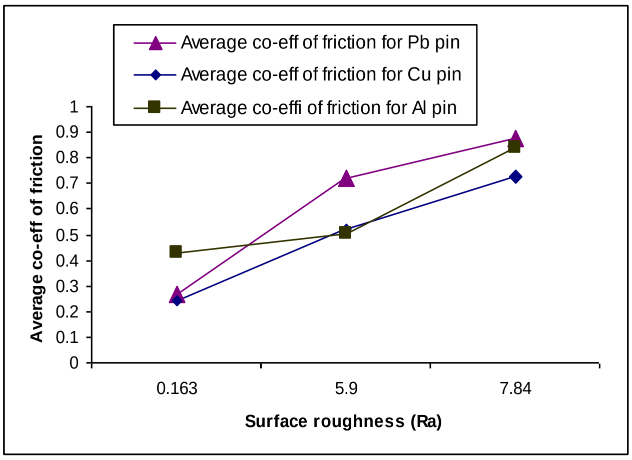


Fig. 9 (c): The variation of average co-efficient of friction with surface roughness (Ra) for Pb, Cu and Al pins slid on steel surfaces when θ= 2 degree

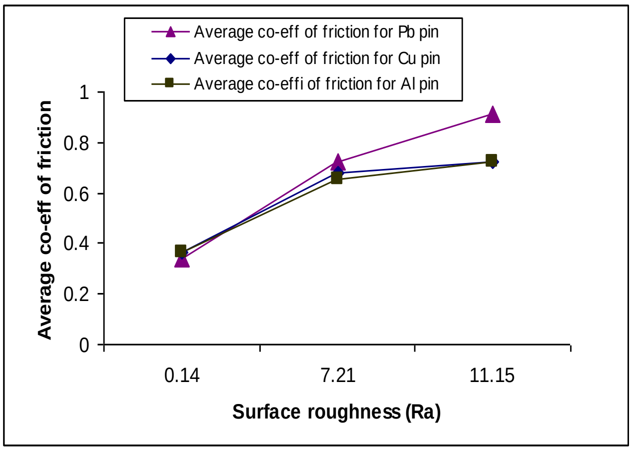


Fig. 9 (d): The variation of average co-efficient of friction with surface roughness (Ra) for Pb, Cu and Al pins slid on steel surfaces when θ= 2.5 degree

The average co-efficient of friction as shown in figure 9(a), 9(b), 9(c) and 9(d) for all pins in general is found to increase with increase in surface roughness of the harder steel surface . The co-efficient of friction for lead was found to monotonically increase with surface roughness Ra irrespective of plate inclination angle. Similar trend was not obtained for copper and aluminium pins.

The experiments showed larger extension of dependency of co-efficient of friction with respect to morphology of surfaces.

The transfer layer on EN8 steel plates and pin surfaces when lead, copper and aluminium slid were studied using scanning electron microscope (SEM) for understanding the dependency of co-efficient of friction on morphology of surfaces.

The scanning electron micro graphs (SEM) of transfer layer on EN8 surfaces are shown in figure 10, 11 and 12.The scanning electron micro graphs (SEM) of pins are shown in figure 13, 14 and 15.

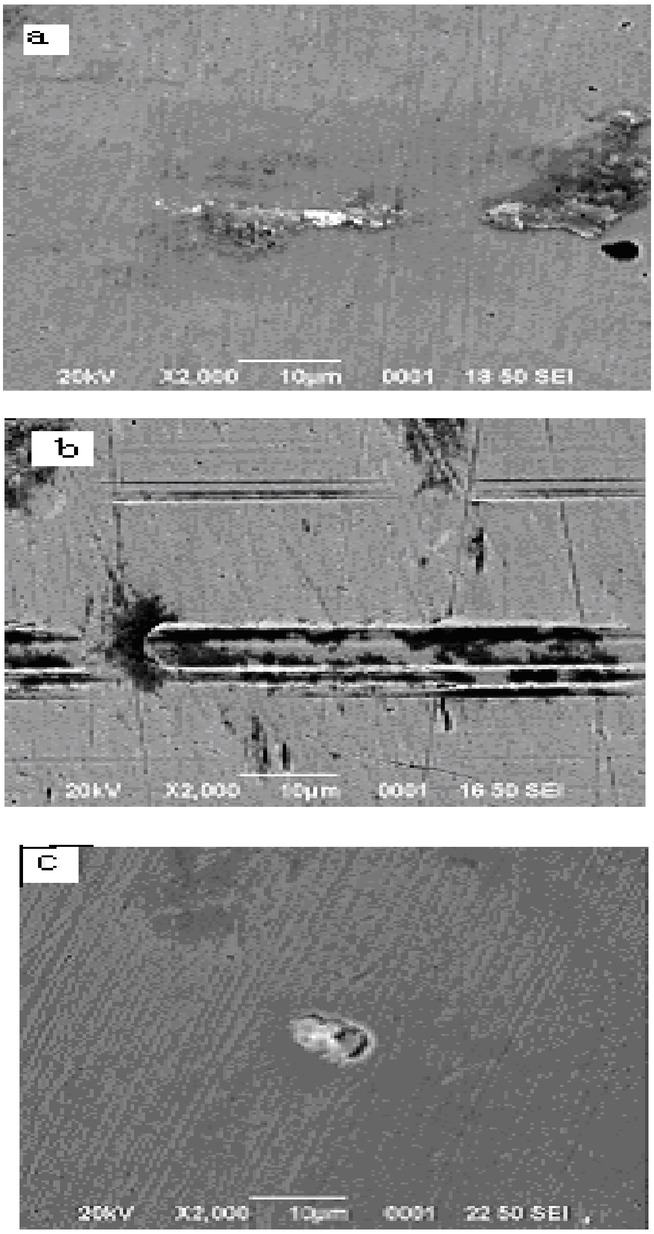


Fig.10 (a) (b) and (c): SEM micrographs showing lead, copper and aluminium transfer layer on ground EN8 steel surface (SiC wheel polished)(X2000)

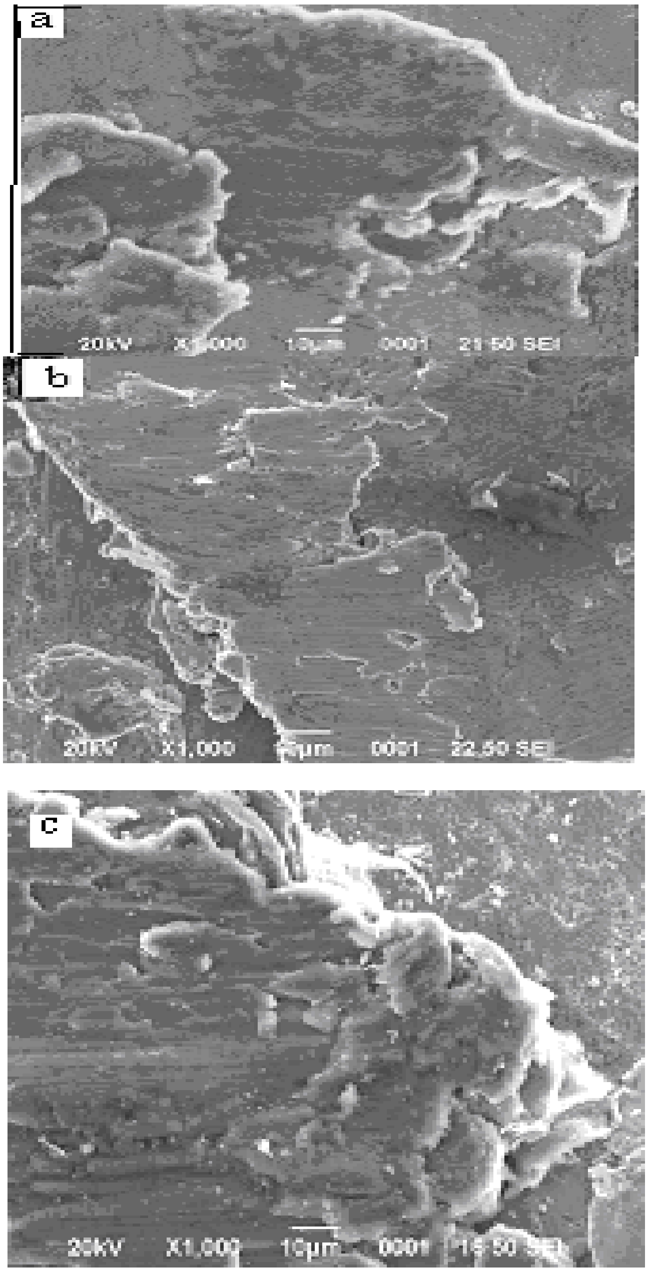
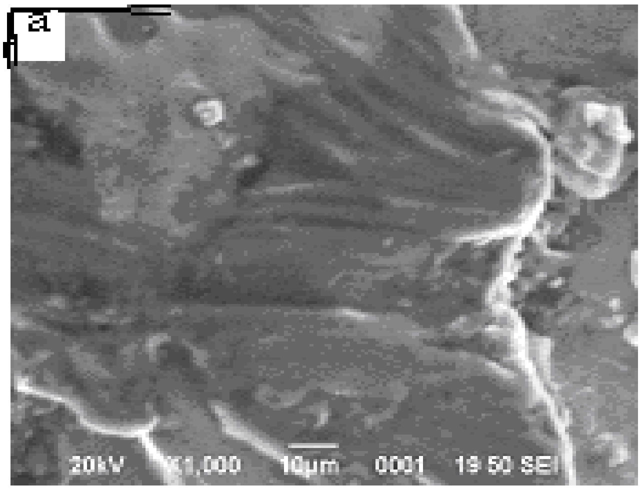


Fig.11 (a) (b) and (c): SEM micrographs showing lead, copper and aluminium transfer layer on shot blast EN8 steel surface (X1000).



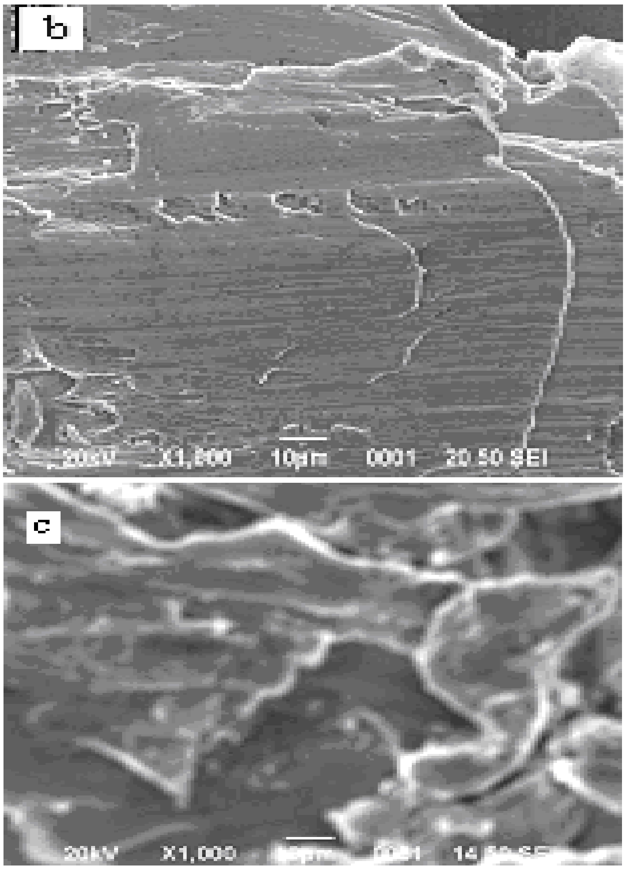
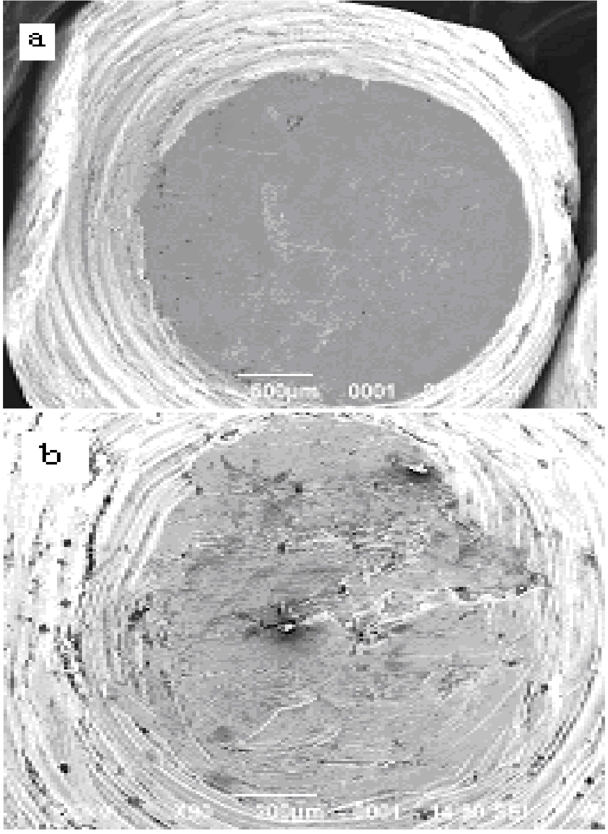


Fig.12 (a) (b) and (c): SEM micrographs showing lead, copper and aluminium transfer layer on electric discharge machined EN8 steel surface (X1000)

The transfer layer in figure 10, 11 and 12 revealed that the quantity of transfer layer for lead is more compared to copper and aluminium.

The energy spent in forming quantum of transfer layer explains the difference in friction for lead, copper and aluminium pins



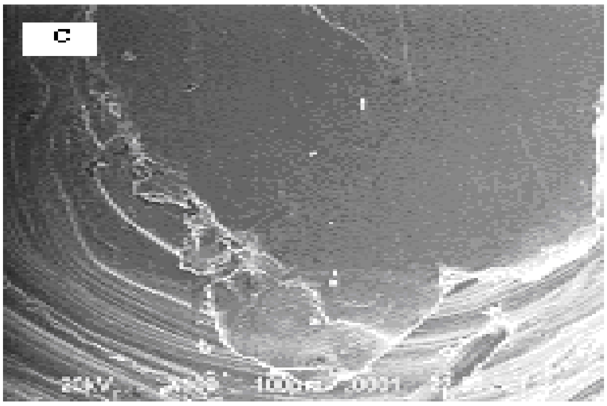


Fig.13 (a) (b) and (c): SEM micrographs of lead, copper and aluminium pins after sliding on EN8 steel surface (SiC wheel polished)

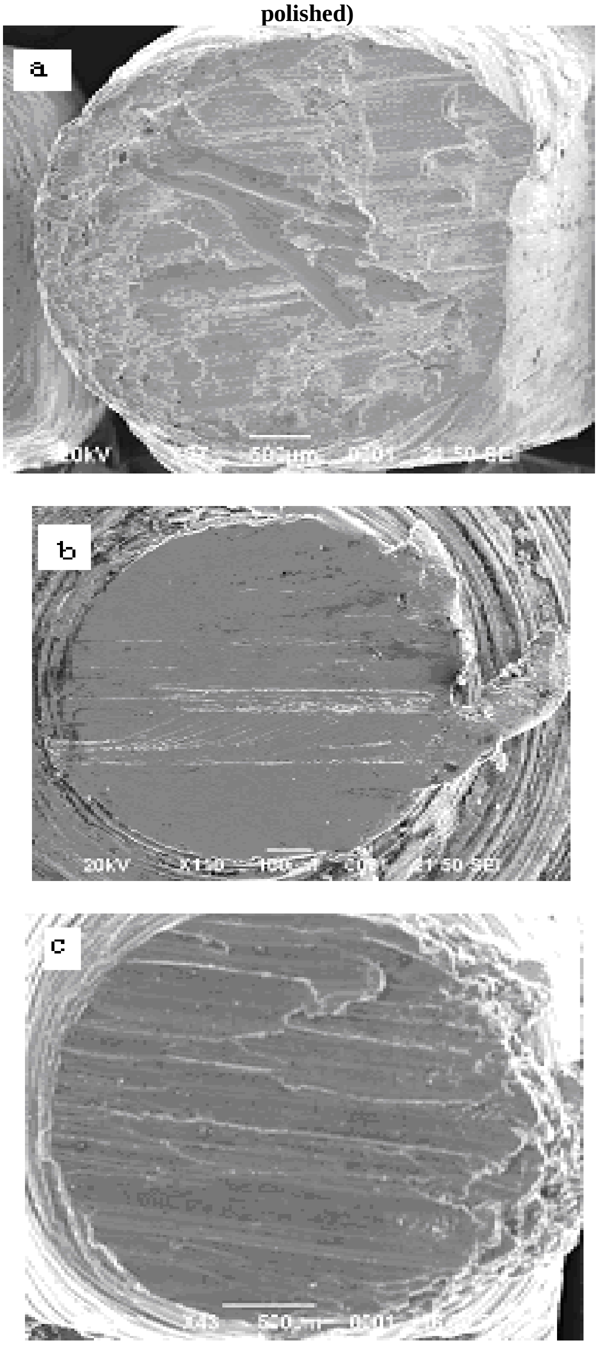


Fig.14 (a) (b) and (c): SEM micrographs of lead, copper and aluminium pins after sliding on shot blast surface.

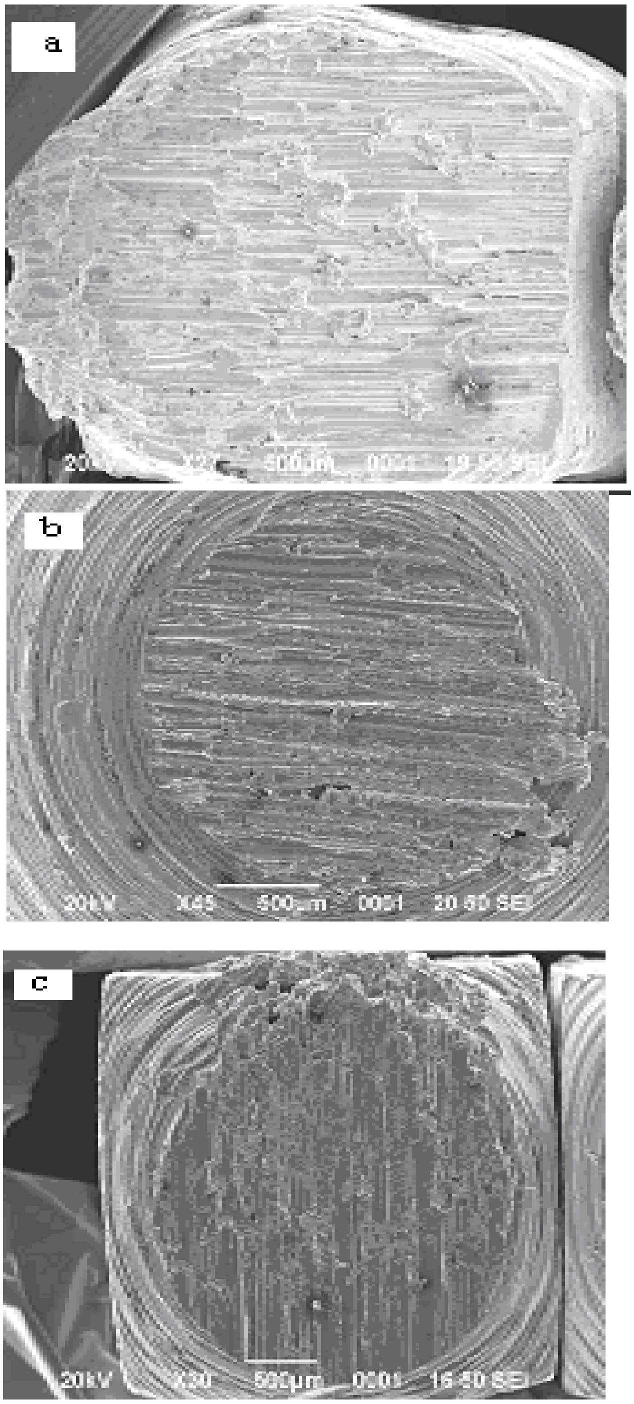


Fig.15 (a) (b) and (c): SEM micrographs of lead, copper and aluminium pins after sliding on electric discharge machined surface.

The lead pin surface is smoother for all steel surfaces compared to copper and aluminium. The smoothness of the lead pin surface is due to softness of the material.

IV. CONCLUSIONS

In the present investigation a pin-on-plate sliding tester was used to identify the effect of surface morphology and hardness on co-efficient of friction and transfer layer which characterizes the tribological behavior while lead, copper and Aluminum (Al6082) pins were slid against steel (EN8) plates for different plate inclination angles under dry conditions in ambient environment.

The conclusions of the experiments are as follows:

- The dependence of co-efficient of friction against sliding distance showed the steadiness of sliding.
- The average co-efficient of friction was found not to vary much with plate inclination angle.
- The average co-efficient of friction was found to increase with surface roughness (Ra).The increase in co-efficient of friction was found to be related to transfer layer formation.
- The quantum of transfer layer was more as the co-efficient of friction increases.

ACKNOWLEDGEMENTS

The author thanks professor S.V.Kailash, Department of mechanical engineering, IISc, Bangalore, India for providing lab facilities to conduct experiments. Also the author thanks the Principal, UVCE, Bangalore, India for providing SEM facilities.

REFERENCES

1. J. F. Archard, “Elastic deformation and the laws of friction”, Proceedings of Royal. Society of London, Ser. A (243), 1957, 190-205.
2. T. Nellemann, N. Bay and T. Wanheim, Real area of contact and friction stress – The role of trapped lubricant, Wear 43(1), 1977, 45-53.
3. J. R. Whitehead, Surface deformation and friction of metals at light loads, Proc. Royal. Soc., London, A (201), 1950, 109-124.
4. F. P. Bowden and D. Tabor, The friction and lubrication of solids, volume-I; Clarendon Press, Oxford, UK, 1950.
5. K. Endo and H. Goto, Effects of environment on fretting fatigue, Wear, 48(2), 1978, 347-367.
6. Y. Tsuya, Microstructure of wear, friction and solid lubrication, Tech. Rep. of Mech. Engg. Lab., no. 81,Tokyo, Japan, 1975.
7. K. Hiratsuka, A. Enomoto, T. Sasada, Friction and wear of Al2O3, ZrO2 and SiO2 rubbed against pure metals, Wear, 153(2), 1992, 361-373.
8. H E Staph ,P.M. Ku, H J Carper, Effect of Surface Roughness and Surface Texture on Scuffing Mechanism and Machine Theory 8(1973) 197-208.
9. M M Koura, The effect of surface texture on friction mechanisms, Wear 63(1980) 1-12.
10. P L Menezes, Effect of surface roughness parameter and grinding angle on co-efficient of friction when sliding of Al-Mg alloy over EN8 steel, Transactions of ASME:Journal of Tribology 128(2006) 697-704.

AUTHORS PROFILE

Mr .M Basavaraju, DME, B.E, M.E, MISTE presently working as Selection grade lecturer in the Department of Mechanical Engineering, Government Polytechnic, Channasandra, Bangalore. Holds a teaching experience of 18 years and a research experience of 4 years. Pursuing Ph D on “Effect of surface morphology on friction and transfer layer formation” at Bangalore University, Bangalore, India.

Dr.S Ranganatha, B.E, M.E, Ph D(IISc). Presently working as Professor, Department of mechanical engineering, University Visveswaraya College of Engineering, Bangalore, India. Holds an industrial experience of 5 years and teaching experience of 22 years.