An Empirical study Examining the Impact of Various Surface Morphologies of Materials on the Development of a Transfer Layer in Dry Circumstances

Mahesh [1], Ravi M Tilavalli [2], G Veerabhadrappa [3]

[1] *Department of Mechanical Engineering, Government polytechnic Aurad, Karnataka, India.*
[2]*Department of Mechanical Engineering, Government polytechnic Harihara, Karnataka, India.*
[3] *Department of Mechanical Engineering, Government polytechnic Karatagi, Karnataka, India.*

ABSTRACT

The tribological behavior of interacting surfaces depends on micro and macro surface morphology. Contacting surface friction and wear depend on surface hardness. Surface morphology of a tool is important because it regulates interface tribological behavior and product surface quality. Industry uses hot and cold metal forging to make technological components. Die surface condition affects engineering component surface finish in such production processes. Tribological events during die-component contact greatly affect engineering component surface finish. Die surface form, hardness, and lubrication affect product finish. Die surface shape, hardness, and lubrication affect product surface finish. This study employed a pin-on-plate sliding tester to examine how surface morphology, lubrication, and hardness affect the transfer layer's coefficient of friction and transfer, which determines tribological behavior. Shot blasting, electric discharge machining, and grinding (silicon carbide wheel polishing) changed mild steel (EN8) plate surfaces. A three-dimensional optical profilometer measured steel plate surface roughness to define their shape. Pushing lead, copper, and aluminum (Al6082) pins over steel plates tests hardness. Trials tested plate inclination angles of 1, 1.5, 2, and 2.5 degrees. Normal load was changed from 1 to 150N throughout experiments. The experiments were done in lubricated conditions. Transfer layer development on plate and pin surfaces was examined using a scanning electron microscope. Surface shape affects friction and transfer layer creation on the tougher surface after lubrication. Quantity of transfer layer formation increases with surface roughness.

Keywords: *Empirical study, Morphology, Friction, Tribological behavior, Dry circumstance.*

1. INTRODUCTION

Due to the force, heat, and electrical transmission at the contacting interface between two components in engineering applications, these contacting surfaces must be thoroughly investigated. Several scientific studies have sought to explain interface behavior. They found that contact happens across a smaller percentage of space, called the real area of contact [1-4]. Under the microscope, the contacting surface has asperities rather than smoothness.Tensions arise when the true area of touch is less than the perceived area. The design stresses surpassed the predicted engineering stresses based on apparent area of contact, while the actual stresses exceeded the material's yield stresses, causing elastic, plastic deformation, and interface fracture [2]. Contact is uncertain due to surface imperfections. All studies estimate contact interface stresses using Hertzian contact theory, which may be applied to non-conforming surfaces [3]. In his sliding contact solution, Mindlin[5] assumed that the coefficient of friction between two interacting faces is the proportionality constant and that shear stress at contact surfaces equals normal stress. Archard [6] used surface asperity elastic deformation to prove Amontons' rule. The elastic deformation of multiple asperities may explain the Amontons' rule for confirming surfaces, but not for single asperities. Similar results are seen for lubricated surfaces. Hertzian contact theory was used by Greenwood [7] and others to predict contact surface stresses and deformation in numerous contacts. These strategies failed to explain the interface in-elastic contact phenomena. Bowden and Tabor [8] adapted these ideas to electrical and frictional problems. Staph used a caterpillar disc tester to study how surface texture and roughness affect scuffing [9]. Contact concerns dominated attempts to understand extrudate surface smoothness and tolerance during extrusion. Extrusion testing showed that at least three enhanced the finish [10]. Narrowing the choke angle improved product polish. Surface polish changed periodically due to transfer layer thickness fluctuations. Nitrating and sintering polished and parallel ground dye created the best surface. [11]. Archard and Hirst [12] examined material combinations' wear at 50g to 10kg and 2 to 60cm per second. Because surface properties change with load, the wear rate is no longer proportional to load. Azushima and Sakuramoto[13] tested die-work piece tribilogy using tension bending. When lubricated, surface roughening was prevalent with a constant coefficient of friction at lower average contact pressure, whereas asperities flatten with a reduction in friction at higher average contact pressure. Theoretical model by Koura [14] predicts adhesion and abrasion friction coefficients while accounting for surface roughness. Results showed that frictional values varied with surface roughness. Whitehead [15] tested different materials to prove Amontons' law. After electrolytically polishing copper, minuscule weights did not obey Amontons' law during sliding testing. Differing from Amontons' law caused an oxide layer. Lubrication experiments were done. These investigations did not support Amontons' rule, although dry sliding did. Kerridge and Lancaster [16] investigated wear basics using extreme wear. Brass vs. a harder material component caused metallic debris. Two wear phases were found. Material transport and transfer layer debris were involved. Nellemann and Bay [17] originally modeled how normal load, asperities slope, friction factor, and lubricant bulk modulus affect friction and actual area of contact. The findings showed only normal pressure and bulk modulus matter. Theng-Sheng Yang [18] created a novel model to predict lubricated product surface roughness. When lubricated sheet metal was made, our model predicted the surface better. Rigney and Hirth [19] devised a friction source model for protracted sliding. Plastic deformation at the near surface underpins this idea. The model correctly predicted friction-load, sliding distance, surface temperature, and microstructure. Suh and Sin [20] presented a novel friction theory that included surrounds and sliding distance. Mechanical qualities like hardness affect sliding surface compatibility more than relative solubility, the hypothesis states.

2. EXPERIMENTAL PROCEDURE

Figure 1 shows how lead, copper, and aluminum (Al 6082), which are softer than mild steel (EN8), are machined into the shape of pins. Figure 2 depicts the dimensions of machined EN8 steel in plate form. Every measurement is in mm.

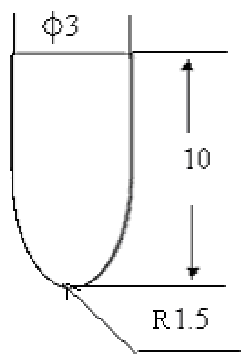

Fig.1. Dimensions of pin

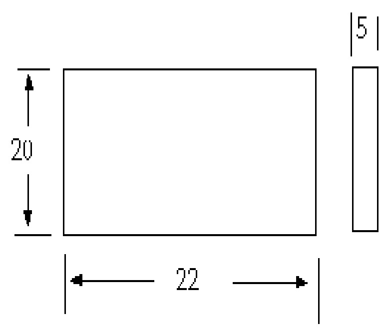

Fig. 2.Specifications of Mild Steel (EN8) Plate

Three manufacturing procedures were used to fine-tune the EN8 flat surfaces: sandblasting, grinding (Silicon Carbide wheel polishing), and electric discharge machining (EDM).A non-contact three-dimensional optical profilometer was used to examine the surfaces of the modified plates. Every surface had its average surface roughness metric, Ra, recorded.

Calculation of the mean surface roughness Electric discharge machined (EDM) surfaces had a Ra value of 7.84µm, sandblast surfaces had a Ra value of 5.90µm, and ground surfaces had a Ra value of 0.17µm. Ra was greatest on the electric discharge machined surface and lowest on the ground (Silicon Carbide wheel polished) surface. The three surfaces were found to be dominated by peaks.

To remove any buildup of work-hardened coatings, the pins were electropolished. The steel plates and pins were cleansed extensively using an aqueous washing solution before to every experiment. The next step was to use an ultrasonic cleaner to clean the pins and plates with acetone.

The studies were carried out using an inclined Scratch tester, which is another name for a pin-on-plate sliding tester. The impact of load on the coefficient of friction might also be determined using it. Figure 3 is a schematic depicting a pin and an inclined plate.

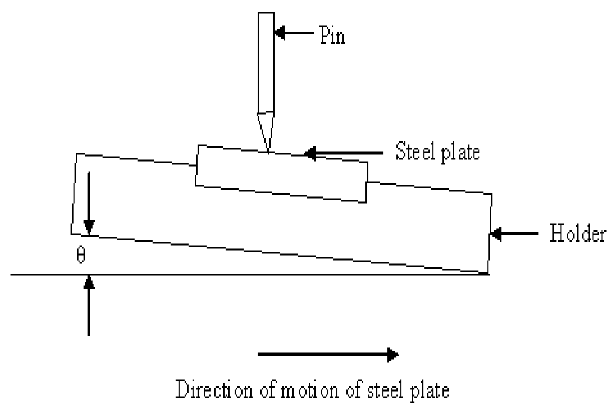

Fig .3: Diagram of the pin-on-plate mechanism with an inclined steel plate.

The polished pins were displaced at a certain speed in the opposite direction of the polished and lubricated EN8 steel plates, spanning a sliding distance of about 10 mm along the inclined surface, from the bottom to the top. A computerized data gathering system was used to continually quantify shear and normal stresses. During the test, the standard load was adjusted between 1 and 150 N. The formula was used to compute the co-efficient of friction (μ), which is the ratio of shear force (T) to normal force (N) based on the measured forces.

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

Experiments were undertaken to investigate various characteristics under lubricated conditions. The variables considered were the surface roughness (Ra), the hardness of the pin, and the inclination angle of the plate (θ). The pins used were made of lead, copper, and aluminum. The Ra parameter was used to quantify the surface roughness. The plate had inclination angles of 1, 1.5, 2, and 2.5 degrees. Sliding tests were performed on each plate under lubricated circumstances for each parameter in the ambient environment. A 0.05ml quantity of engine oil lubricant (SAE 40, API rating SJ class) was applied to the steel surface, and further tests were conducted. The viscosity of the lubricating oil was measured to be 40 cSt at a temperature of 40 degrees Celsius. The tests were done for varied surface roughness levels under lubricated conditions, for each inclination angle. Experiments were conducted to produce five lubricated wear tracks that were parallel to each other on a single plate, with each track corresponding to a different inclination angle. The pins and EN8 flat surface were examined using a scanning electron microscope (SEM) after the experiment. This was done to gain insight into the source of the transfer layer and its correlation with the estimated friction coefficient.

3. RESULTS AND DISCUSSION

For surfaces that have been ground (SiC wheel polished) or sandblasted, lead pins have a lower coefficient of friction than aluminum and copper ones. Compared to a lead pin, an aluminum pin had the lowest coefficient of friction when tested on an EDM surface. On top of that, Ra is directly proportional to the coefficient of friction. An average frictional coefficient and a steady state are the results of each sliding experiment. The impact of pin hardness, surface roughness, and plate inclination angle on flat surfaces may be calculated using these average friction coefficients.In dry circumstances, lead, copper, and aluminum pins were moved against ground (silicon carbide polished), shot blast, and electric discharge machined steel surfaces. The average coefficient of friction and its connection to plate inclination angle are shown in Figures 4(a), (b), and (c).

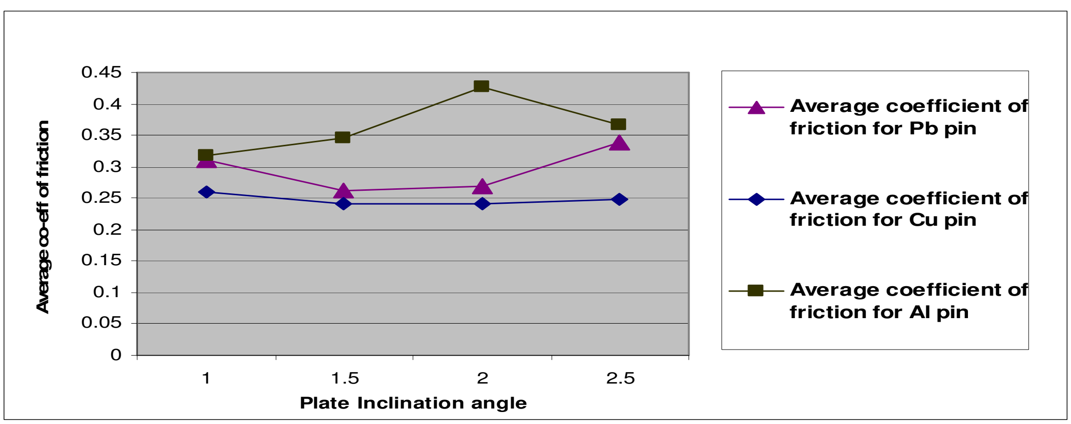

Fig. 4 (a): The average coefficient of friction changed with the angle of the plate when Pb, Cu, and Al pins moved on ground (SiC) steel surfaces when the steel was dry.

As seen in figure 4(a), the average coefficient of friction at a 2 degree angle for various pin materials, with the exception of aluminum, did not exhibit a significant variation with plate inclination angle while sliding over ground (SiC) steel surfaces. A greater coefficient of friction was observed for an aluminum pin at an inclination angle of 2 degrees compared to other surface inclination angles.

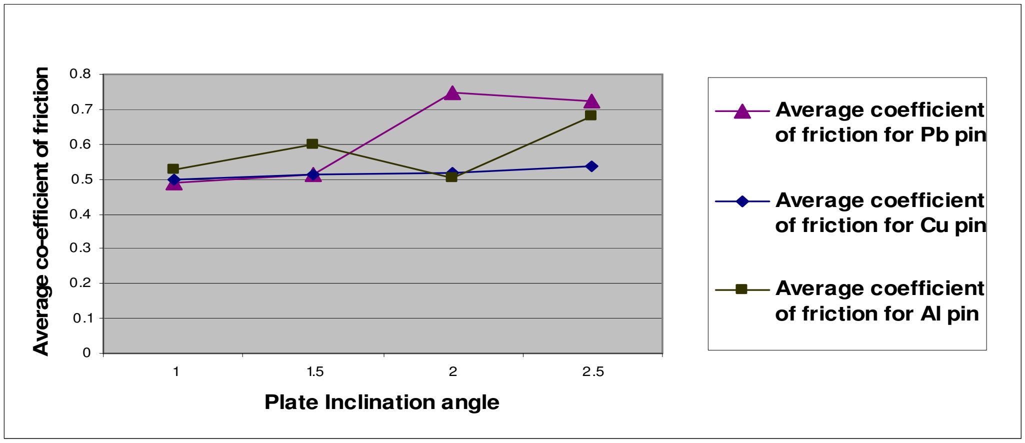

Fig. 5(b): The average coefficient of friction changed with the angle of the plate when Pb, Cu, and Al pins moved on steel surfaces that had been shot-blasted and were dry.

Figure 4(b) shows that, for most inclination angles of the plates, the average coefficient of friction for sand blast surfaces does not change much. However, at 2 and 2.5 degrees of inclination, there is a little variation in the average coefficient of friction value for the lead pin.

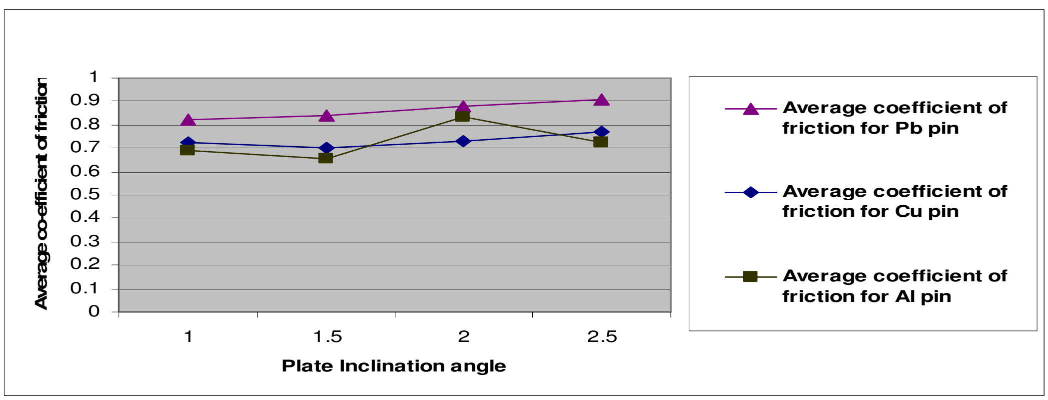

Fig. 4(c): The average coefficient of friction changed with the angle of the plate when Pb, Cu, and Al pins moved on steel surfaces that had been cut with an electric discharge when the steel was dry.

Electric discharge machined steel surfaces, similar to ground (SiC) steel surfaces, have an average coefficient of friction that does not change significantly with plate inclination angle (Figure 4(c)).

Using a scanning electron microscope (SEM), researchers investigated the transfer layer on EN8 steel plates and pin surfaces as lead, copper, and aluminum slid. This allowed them to get a better understanding of how the coefficient of friction impacts the surface morphology.The transfer layer on EN8 surfaces is shown in scanning electron micrographs

(SEM) in Figures 5, 6, and 7.Scanning electron micrographs (SEM) of pins are shown in Figures 8, 9, and 10.

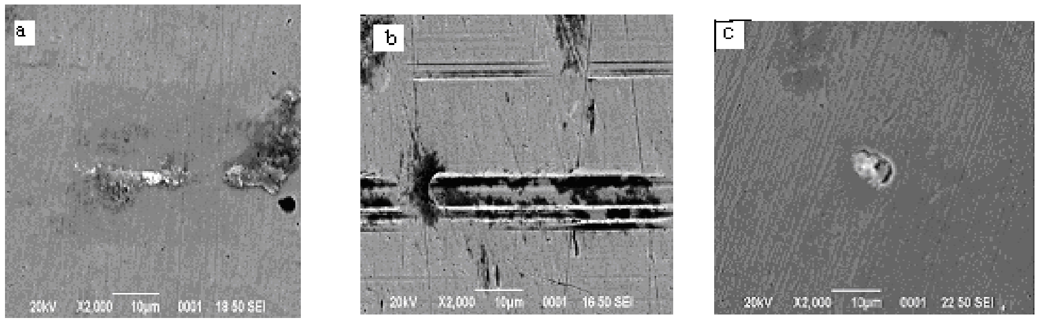

Fig.5 (a) (b) and (c): SEM micrographs showing lead, copper and aluminium transfer layer on ground EN8 steel surface (SiC wheel polished) under dry condition.

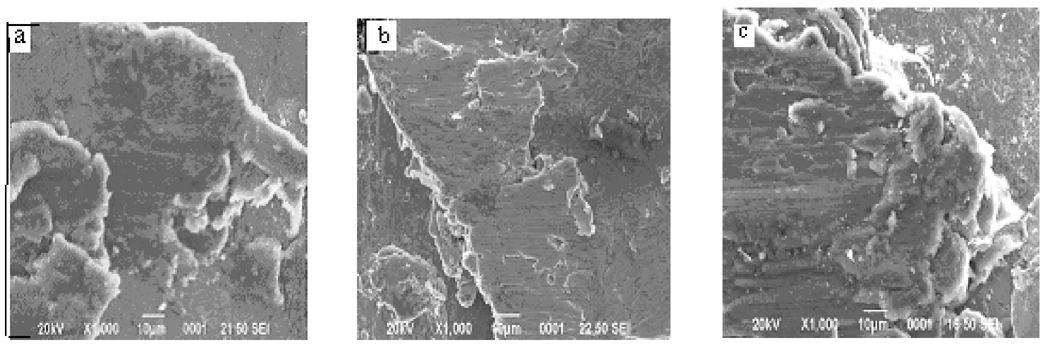

Fig.6 (a) (b) and (c): SEM micrographs showing lead, copper and aluminium transfer layer on shot blast EN8 steel surface under dry condition.

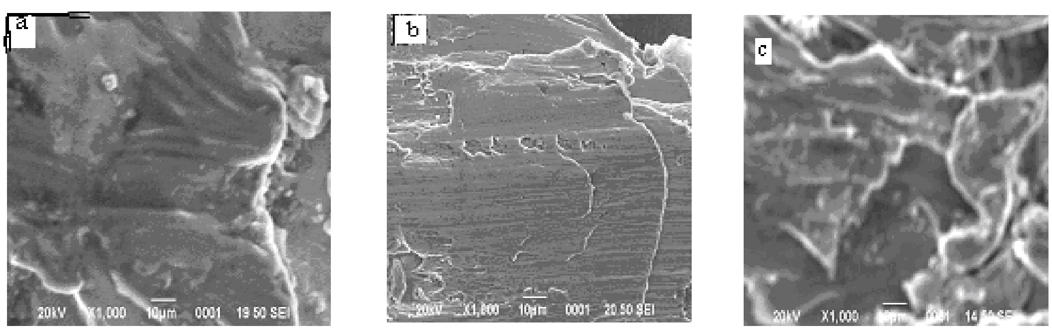

Fig.7 (a) (b) and (c): SEM micrographs showing lead, copper and aluminium transfer layer on electric discharge machined EN8 steel surface under dry condition.

The difference in friction between lead, copper, and aluminum pins may be explained by the amount of energy that is expended during the formation of the quantum of transfer layer.

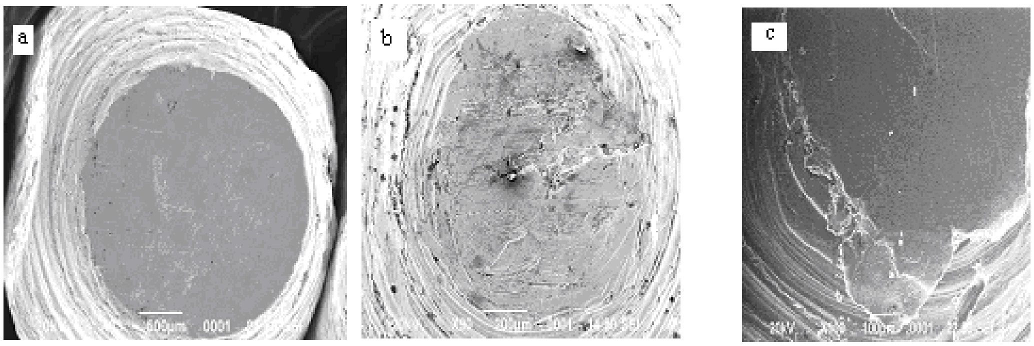

Fig. 8 (a) (b) and (c): SEM micrographs of lead, copper and aluminium pins after sliding on EN8 steel surface (SiC wheel polished) under dry condition.

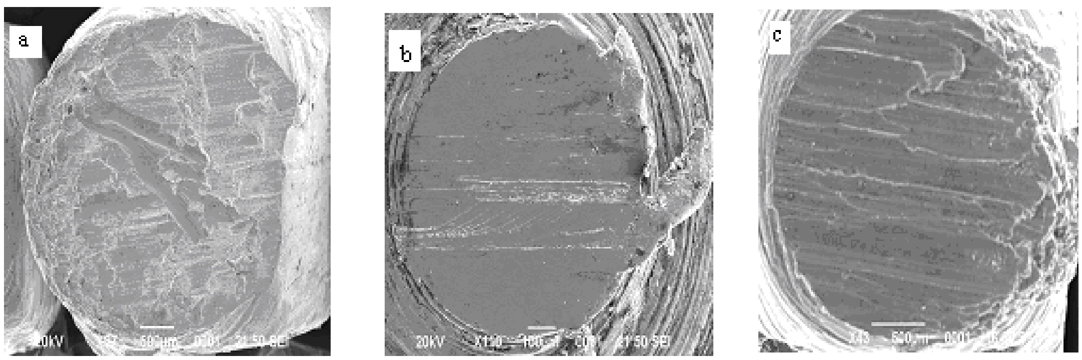

Fig.9 (a) (b) and (c): SEM micrographs of lead, copper and aluminium pins after sliding on hot blast surface under dry condition.

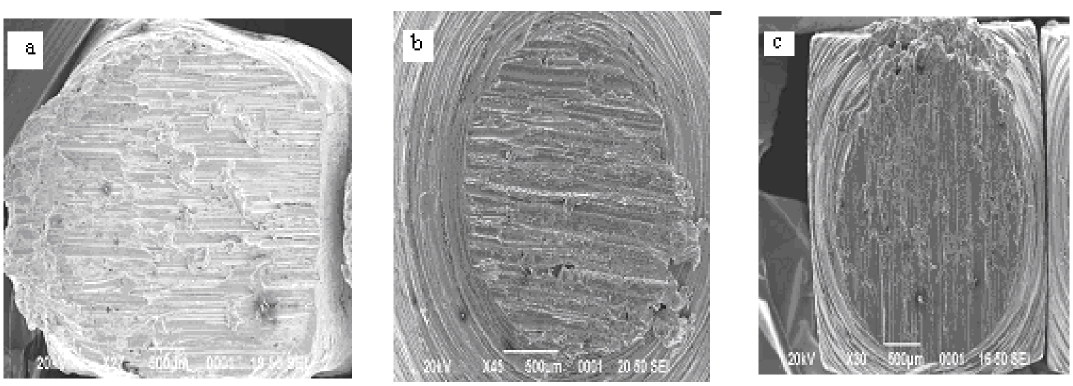

Fig.10 (a) (b) and (c): SEM micrographs of lead, copper and aluminium pins after sliding on electric discharge machined surface under dry condition.

The surface of the lead pin is smoother on all steel surfaces than it is on copper and aluminum or any other material. Due to the fact that the material is soft, the surface of the lead pin is smooth.

4. CONCLUSIONS

In the current study, a pin-on-plate sliding tester was used to determine the effect of surface morphology and hardness on the coefficient of friction and transfer layer, which characterizes tribological behavior, when lead, copper, and aluminum (Al6082) pins were slid against steel (EN8) plates at various plate inclination angles in an ambient environment under lubConclusions of the experiment. The coefficient of friction and sliding distance under lubricated circumstances stabilized sliding. The average coefficient of friction remained constant as plate inclination angle increased under lubrication. Lubricated surface roughness (Ra) rises with average friction.The coefficient of friction increased with transfer layer creation. The transfer layer under lubrication rises with friction. Dry circumstances have a greater average coefficient of friction than lubricated situations.

REFERENCES

[1] Y. Tsuya, Microstructure of wear, friction and solid lubrication, Tech. Rep. of Mech. Engg. Lab., 3(81), Tokyo, Japan, 1975.

[2] R. Holm, P. Charsley A study of indentation in an AlCu Mg alloy, Materials Science and Engineering: A, Volume 229(1–2), (1997), 10-22

[3] K.L.Johnson, Proceedings of institute of Mechanical Engineers, volume 196(1982)363-378.

[4] S.Ranganatha, Ph.D. thesis, 2008, Transfer layer formation and friction in extrusion of aluminium; an experimental study using a high temperature vacuum based pin-on-disc machine. Department of Mechanical engineering, IISc, Bangalore, India

[5] R.D.Mindlin, Journal of Applied Mechanics, volume 71(1949)259

[6] J. F. Archard, Elastic deformation and the laws of friction, Proceedings of Royal. Society of London, Ser. A, 243 (1957), 190-205.

[7] J.A.Greenwood and J.B.P.Williamson, Proceedings of Royal. Society of London, Ser. A, 295 (1996) 300-319.

[8] F P Bowden, D Tabor, The friction and lubrication of solids, Clarendon press, Oxford, UK, 1954.

[9] H E Staph,P.M Ku, H J Carper, Effect of Surface Roughness and Surface Texture on Scuffing Mechanism and Mechine Theory 8(1973) 197-208.

[10] S.Abtahi,, Ph.D Thesis 1995 ,Department of Mechanical Design and materials Technalogy,The Norwegian institute of Technalogy,University of Trondenhim, Trondenhim, Norway,1995.

[11] W.W.Thedja, K.B.Muller and D.Ruppin, Proceedings of the 5th international Extrusion Technalogy seminar, Chicago (1992)467-474.

[12] J. F. Archard and W. Hirst, The wear of metals under unlubricated conditions, Proceedings of Royal. Society of London A, 236 (1956) 397-410.

[13] Azushima, M. Sakuramoto, Effects of Plastic Strain on Surface Roughness and Coefficient of Friction in Tension-Bending Test, CIRP Annals - Manufacturing Technology, Volume 55(1), (2006), 303-306.

[14] M M Koura, The effect of surface texture on friction mechanisms, Wear 63(1980) 1-12.

[15] J. R. Whitehead, Surface deformation and friction of metals at light loads, Proc. Royal. Soc., London, A, 201, 1950, 109-124.

[16] M. Kerridge and J. K. Lancaster, The Stages in a Process of Severe Metallic Wear Proc. R. Soc. Lond. A , 236(1956) 250-264.

[17] 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.

[18] Theng-Sheng Yang, Prediction of surface topography in lubricated sheet metal forming, International Journal of Machine Tools and Manufacture, Volume 48 (7–8)(2008), 768-777.

[19] D. A. Rigney and J. P. Hirth, Plastic deformation and sliding friction of metals, wear, 53(2), 1979, 345-370.

[20] N. P. Suh and H. C. Sin, The genesis of Friction, Wear, 69(1), 1981, 91-114

[21] M. Khonsari and E.R. Booser ,"Applied Tribology 2e: Bearing Design and Lubrication" © 2008 John Wiley & Sons, Ltd

[22] ASM Handbook Committee (2002); ASM Handbook. Friction, Lubrication and Wear Technology. U.S.A., ASM International. Volume 18

[23] John A Williams, (2005). "Wear and wear particles - Some fundamentals"; Tribology International 38(2005): 863-870