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Experimental Investigation of Different Material Surface Morphology on Formation of Transfer Layer

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Abstract: ***Metal is made both hot and cold in the industrial sector to make technological components. The surface condition of the dies used in these manufacturing processes is one of the many factors that define the surface quality of engineering components. The tribological phenomena at the die and component contact has a significant impact on the surface finish of engineering components. The surface finish of the products is discovered to be controlled by lubrication, die surface morphology, and die surface hardness. The current study employed a pin - on - plate sliding tester to determine how surface morphology, lubrication, and hardness affect the transfer layer's coefficient of friction and transfer, which define the tribological behavior. Three distinct surface modification techniques, including shot blasting, electric discharge machining, and grinding (silicon carbide wheel polishing), were used to alter the morphology of mild steel (EN8) plate surfaces. A three - dimensional optical profilometer was used to measure the surface roughness characteristics that describe the morphology of the steel plates. Using lead, copper, and aluminum (Al6082) pins pushed across steel plates, the role of hardness is investigated. Plate inclination angles of 1, 1.5, 2, and 2.5 degrees were tested in the experiments. During the experiments, the normal load was changed from 1 to 150N. The experiments were carried out in an ambient setting with lubrication. Using a scanning electron microscope, the development of transfer layers on plate and pin surfaces was examined. The co - efficient of friction and the creation of the transfer layer were shown to be dependent on the tougher surface's surface shape when it was lubricated. With an increase in surface roughness, it is discovered that the quantum of transfer layer development on the surfaces increases.***

Keywords: Lubrication, morphology, friction, hardness, surface and transfer layer formation.

1. Introduction

A detailed examination of the events that occur at these contacting surfaces is necessary due to the degree of force, heat, and electrical transmission that happens at the contacting interface between two components in engineering applications. Numerous studies have tried to explain the behavior at the interface from a scientific perspective. Instead of the apparent area of contact, they have determined that the contact is formed over a smaller percentage of space known as the true area of contact [1 - 4]. Additionally, they discovered that the contacting surface is comprised of asperities rather than being smooth at the microscopic level. Since the true area of contact is less than the apparent area of touch, there are significant tensions there. Even though the design stresses were more than the projected engineering stresses based on apparent area of contact, the actual stresses were greater than the material's yield stresses, which causes elastic, plastic deformation, and fracture at the interface [2]. Asperities on the surfaces result in a situation where the contact is not confirmed. All studies employ Hertzian contact theory, which may be applied to non - conforming surfaces, in one way or another to estimate the stresses at the contact interfaces [3]. In his sliding contact solution, Mindlin [5] made the assumption that the co - efficient of friction between two interacting faces is the same as the proportionality constant and that the shear stress at contact surfaces is proportionate to normal stress. Archard [6] attempted to validate Amontons' rule while taking surface asperity elastic deformation into account. While the Amontons' rule cannot be explained by the elastic deformation of a single asperity, it may be explained in the case of confirming surfaces by the elastic deformation of several asperities. Similar observations are found for lubricated surface. Greenwood [7] and others used Hertzian contact theory to estimate stresses and deformation at contact surface where it is a case of multiple contacts. These attempts could not satisfactorily explain actual contact phenomenon i. e. this approach could not explain the in - elastic contact phenomenon at the interfaces. Bowden and Tabor [8] used these concepts in electrical contact and frictional problems. Staph [9] studied the effect of surface texture and surface roughness on scuffing using caterpillar disc tester. Attempts made to understand the surface finish and tolerance of the extrudate in extrusion process were also basically contact problems. Studies on the number of extrusion trials confirmed that the finish was improved after a minimum of three trials [10]. Providing a smaller amount of choking angle improved the surface finish of the product. It was reported that there was periodic variation in surface finish and this was found to be due to periodic variation in the thickness of transfer layer. It was reported that the best surface was obtained when the surfaces of polished and parallel ground dye were nitrated and sintered. [11]. Archard and Hirst [12] studied wear of wide range of material combination under loads ranging from 50gm to 10kg and speeds of 2 to 60cm per second were studied. It was suggested that the wear rate was proportional to load; in practice this simple relation is modified because the surface conditions depend on load. Azushima, and Sakuramoto [13] conducted a tension bending type of test to understand the tribilogical behaviour between die and work piece showed that in the presence of lubricant, the surface roughening was predominant with constant coefficient of friction at lower average contact pressure, whereas at higher average contact pressure the asperities were found to be flattening with decrease in co efficient of friction. Koura [14], taking surface texture into consideration, developed a theoretical model for estimating adhesion and abrasion friction co - efficient. The results showed that frictional values depend on degree of surface roughness. Whitehead [15] conducted experiments on different materials for validating Amontons's law. It was found that when experiments were conducted on electrolytically polished copper surface; for small loads, the sliding did not obey Amontons's law. The deviation of Amontons's law was attributed to formation of oxide layer. Experiments were also conducted on lubricated conditions. Thus in these experiments the Amontons's law was not justified in general whereas the results of dry sliding confirmed the Amontons's law. Kerridge and Lancaster [16] conducted a severe type of wear to understand basics of wear. The system was brass against a harder material component and conditions gave metallic debris. Two distinct steps in wear were recognized. They were transfer of material and formation of debris from transfer layer. Nellemann and Bay [17] initially developed a model to incorporate the influence of normal load, asperities slope, friction factor and lubricant bulk modulus on friction and real area of contact. Results showed that only normal pressure and bulk modulus have influence. A novel model was created by Theng - Sheng Yang [18] to forecast the product's surface roughness under lubricated conditions. In the event of lubricated sheet metal forming, our model was more accurate in predicting the surface. In the event of persistent sliding, Rigney and Hirth [19] created a model to pinpoint the source of friction. The plastic deformation at the near surface is the basis of this concept. The relationship between friction and load, sliding distance, surface temperature, and microstructure was accurately predicted by the model. Suh and Sin [20] attempted to explain friction using a novel hypothesis that considered the surroundings and sliding distance. According to the idea, mechanical characteristics such as hardness have a greater influence on a sliding surface's compatibility than relative solubility.

2. Experimental Procedure

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

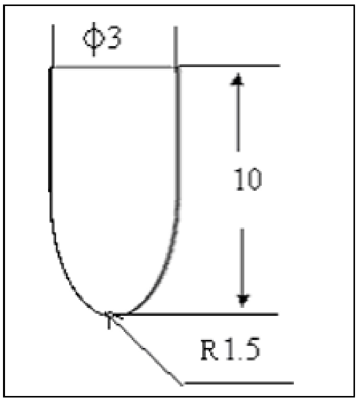

Figure 1: Dimensions of pin

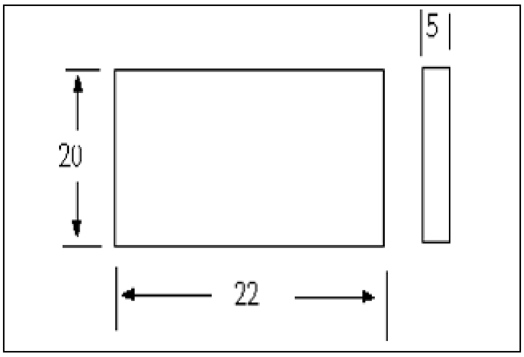

Figure 2: Dimensions of Mild Steel (EN8) Plate

The EN8 flat surfaces were modified by three manufacturing processes, which are grinding (Silicon Carbide wheel polishing), sand blasting and electric discharge machining (EDM). The surface of such modified plates were studied using non- contact type three dimensional optical profilometer. The average surface roughness parameter Ra was measured and recorded for each 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 0.17µm, 5.90µm and 7.84µm. 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.

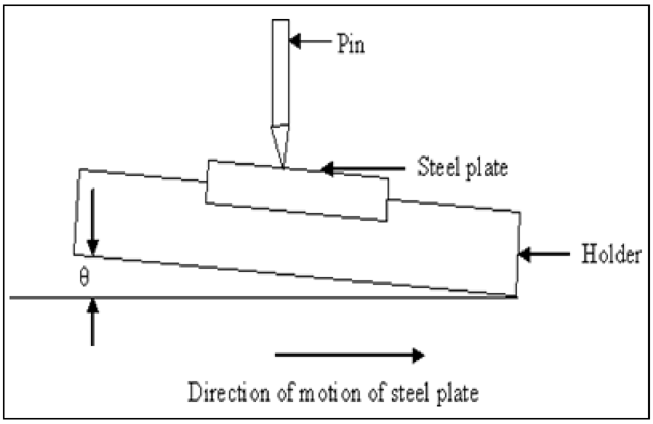

Figure 4: Schematic diagram of Pin on Plate with Inclined steel plate

For a sliding length of around 10 mm, the cleaned pins were moved at a velocity against the cleaned, lubricated EN8 steel plates from the lower end to the upper end of the inclined surface. A computerized data collecting system was used to continually monitor the shear and normal forces. Throughout the test, the usual load was adjusted between 1 and 150N. Using the formula, the co - efficient of friction (μ), or the ratio of the shear force (T) to the normal force (N), was determined from the observed forces.

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

Experiments were conducted for different parameters under lubricated condition. 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 lubricated conditions on each plate in ambient environment. Engine oil lubricant (SAE 40, API rating SJ class) of 0.05ml was applied to the steel surface and tests were performed. The lubricant oil viscosity was found to be 40 cSt at 40 degree Celsius. For each inclination angle the test were conducted for different surface roughness values in lubricated condition. Tests were performed to obtain five parallel lubricated 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.

3. Results and Discussion

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 5 (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 under dry condition.

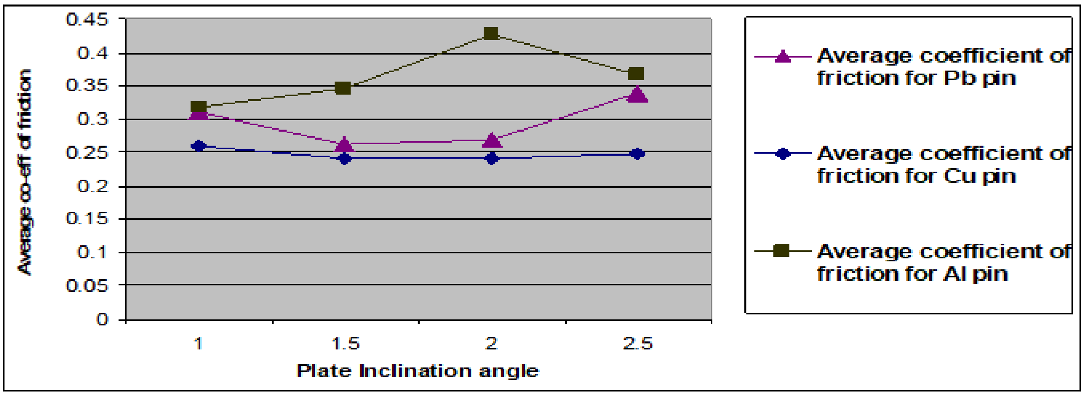

Figure 5 (a): The dependence of Average co - efficient of friction with plate inclination angle when Pb, Cu and Al pins slid on ground (SiC) steel surfaces under dry condition.

The average co - efficient of friction except for aluminium at an angle of 2 degree, for different pin material shown in figure 5 (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.

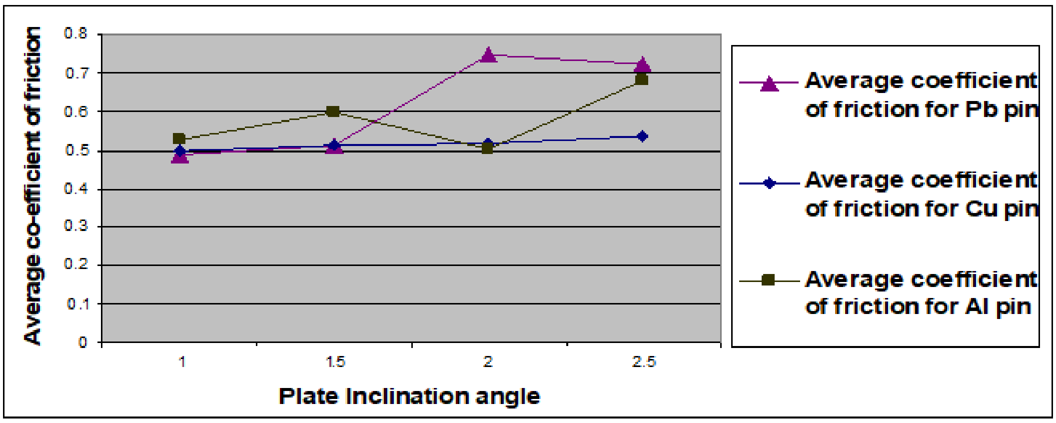

Figure 5 (b): The dependence of Average co - efficient of friction with plate inclination angle when Pb, Cu and Al pins slid on shot blast steel surfaces under dry condition.

The average co - efficient of friction in case of sand blast surfaces which is shown in figure 5 (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.

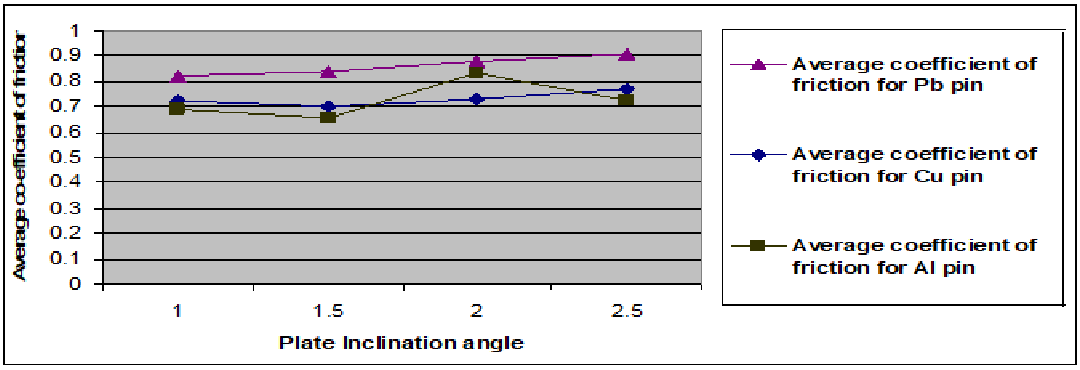

Figure 5 (c): The dependence of Average co - efficient of friction with plate inclination angle when Pb, Cu and Al pins slid on electric discharge machined steel surfaces under dry condition.

The average co - efficient of friction in case of electric discharge machined steel surfaces, which is shown in figure 5 (c), Similar to ground (SiC) steel surfaces, is also found not to vary much with plate inclination angle.

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 6, 7 and 8. The scanning electron micro graphs (SEM) of pins are shown in figure 9, 10 and 11.

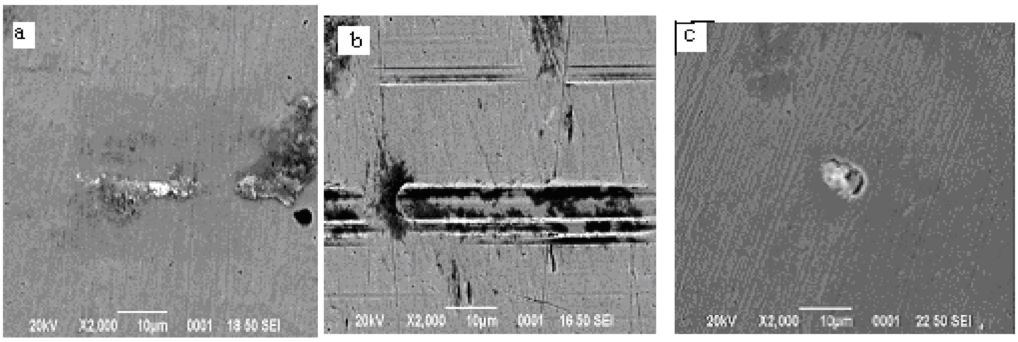

Figure 6 (a) (b) and (c): SEM micrographs showing lead, copper and aluminium transfer layer on ground EN8 steel surface (SiC wheel polished) under dry condition.

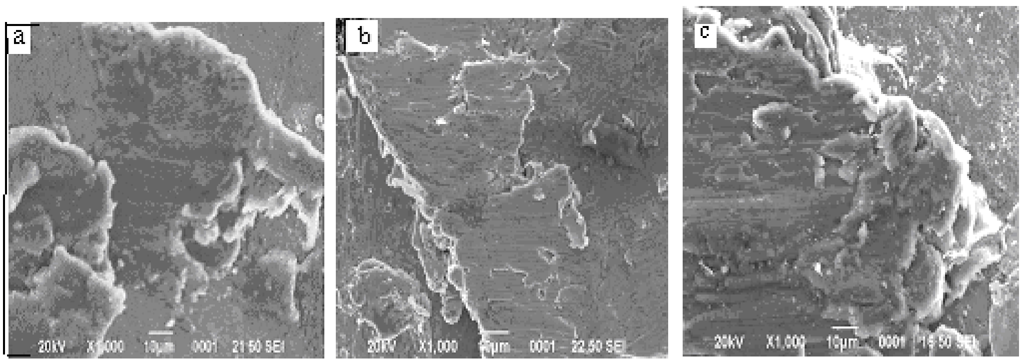

Figure 7 (a) (b) and (c): SEM micrographs showing lead, copper and aluminium transfer layer on shot blast EN8 steel surface under dry condition

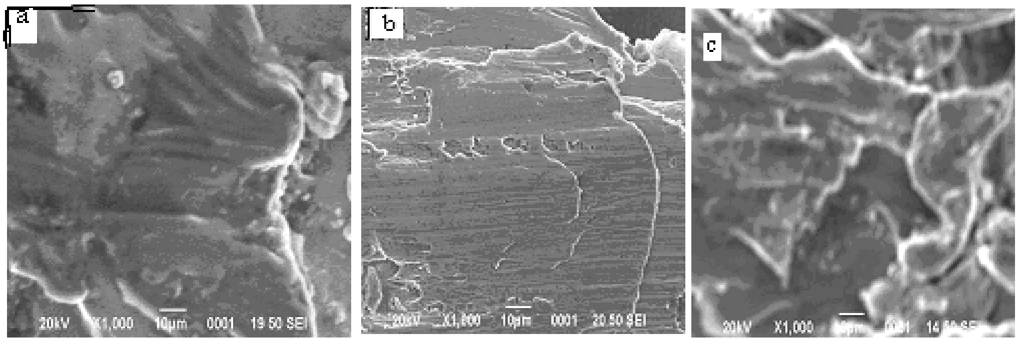

Figure 8 (a) (b) and (c): SEM micrographs showing lead, copper and aluminium transfer layer on electric discharge machined EN8 steel surface under dry condition.

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

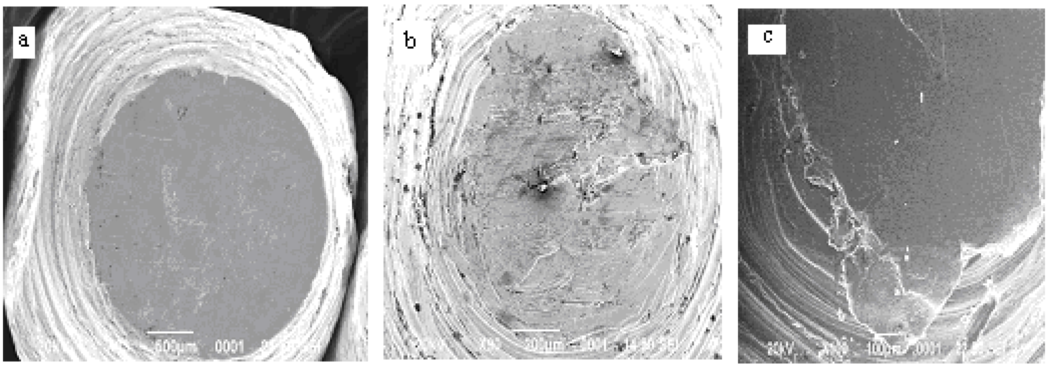

Figure 9 (a) (b) and (c): SEM micrographs of lead, copper and aluminium pins after sliding on EN8 steel surface (SiC wheel polished) under dry condition.

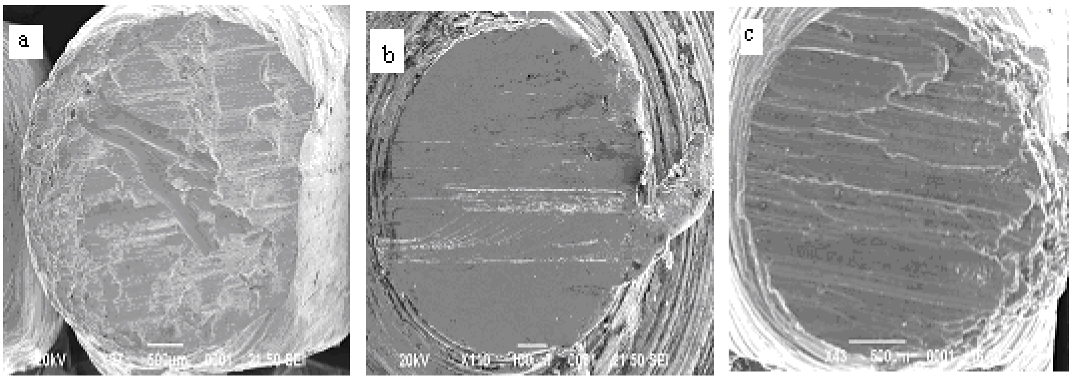

Figure 10 (a) (b) and (c): SEM micrographs of lead, copper and aluminium pins after sliding on hot blast surface under dry condition

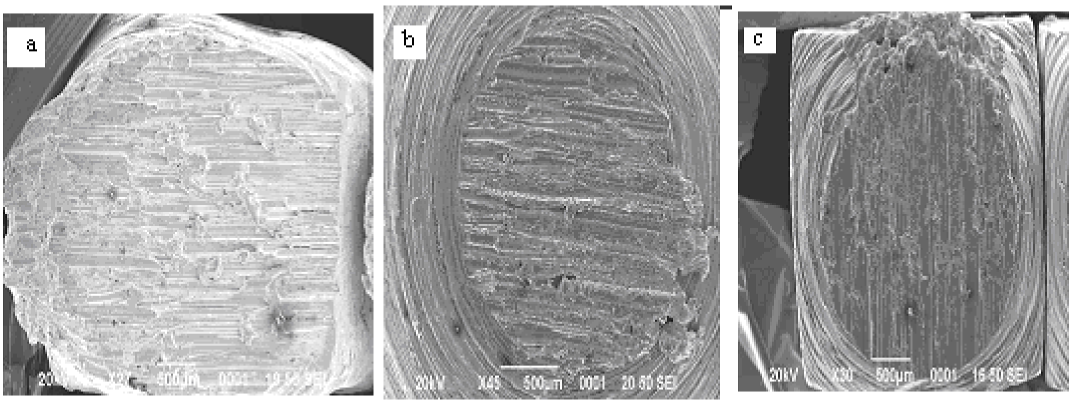

Figure 11 (a) (b) and (c): SEM micrographs of lead, copper and aluminium pins after sliding on electric discharge machined surface under dry condition

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.

4. Conclusions

When lead, copper, and aluminum (Al6082) pins were slid against steel (EN8) plates for various plate inclination angles under lubricated conditions in an ambient environment, the effect of surface morphology and hardness on the co - efficient of friction and transfer layer—which characterizes the tribological behavior—was determined using a pin - on - plate sliding tester in the current investigation. The following are the experiment's conclusions.

- Sliding stability was created by the relationship between the coefficient of friction and sliding distance under lubricated circumstances.
- There was no discernible change in the average coefficient of friction under lubricated circumstances as the plate inclination angle increased.
- Under lubricated circumstances, it was shown that surface roughness (Ra) increased with average coefficient of friction. It was demonstrated that the formation of transfer layers was linked to a rise in the coefficient of friction.
- As the coefficient of friction increases, the quantity of the transfer layer under lubricated conditions increases.
- When compared to lubricated conditions, the average coefficient of friction in dry conditions was found to be higher.

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 Technology, The Norwegian institute of Technology, 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
[24] N. P. Suh, Tribophysics, Prentice - Hall, Inc., Englewood Cliffs, New Jersey, 1986
[25] J. L Meriam; L. G. Kraige (2002). Engineering Mechanics (fifth ed.).; John Wiley & Sons. p.328. ISBN 0471602930
[26] Peter. J. Blau, Friction science and technology: from concepts to application; second edition
[27] 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.
[28] W. Rasp, C. M. Wichern, Effects of surface - topography directionality and lubrication condition on frictional behavior during plastic deformation, J. Mater. Process. Technol.125–126 (2002) 379–386.