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Research Paper

Effects of Friction and Transfer Layer Development on the Morphology of Hard Materials

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Abstract: *Technical components are made by shaping metal using both hot and cold processes in production. The condition of the dies used in different production processes is one of the aspects that impact the surface quality of engineering components. At the point where the die and component make contact, tribological events have a significant influence on the surface finish of engineering components. There are a number of factors that affect the surface finish of a product, including lubrication, the form of the die, and hardness. The pin-on-plate sliding tester was used in this investigation to ascertain the effect of surface morphology, lubrication, and hardness on the transfer layer and coefficient of friction, which characterize tribological behaviour. Three distinct surface modification techniques—grinding (silicon carbide wheel polishing), shot blasting, and electric discharge machining—were used to alter the morphology of mild steel (EN8) plate surfaces. A three-dimensional optical profilometer was used to evaluate the surface roughness parameters that define the morphology of the steel plates. Pins made of lead, copper, and aluminium (Al6082) are moved over steel plates to study the effect of hardness. Three different inclination angles of one, two, and three and a half degrees were used in the experiments. Testing was conducted with a normal load that was varied between 1 and 150 N. The environmental conditions were lubricated before to the experiments. The process of depositing transfer layers onto pin and plate surfaces was examined using a scanning electron microscope. It was shown that, under lubricated circumstances, the shape of the harder surface effects both the coefficient of friction and the formation of transfer layers. It seems that the amount of transfer layer production on surfaces is inversely proportional to their roughness.*

Key words: Friction, Lubrication, Hardness, Surface morphology,Transfer layer formation.

I. INTRODUCTION

The amount of force, heat, and electrical transmission that occurs at the contacting interface of two components in engineering applications needs detailed research of the events that occur at these contacting surfaces. Various research projects have attempted to scientifically investigate the phenomena at the interface. They have identified that the contact is established over a fraction of area called real area of contact instead of apparent area of contact [1-4]. They also identified that the contacting surface on microscopic scale is not smooth but consisting of asperities. The real area of contact, being fraction of apparent area of contact, leads to large magnitude of stresses at the real area of contact. Though the estimated engineering stresses based on apparent area of contact were smaller in magnitude than the design stresses; the actual stresses were large in magnitude than yield stresses of material and which brings about elastic, plastic deformation and fracture at the interface [2]. The surfaces are consisting of asperities which lead to a case of non-confirming contact. Hertzian contact theory which is applicable to non-conforming surfaces is one way or other way is made use by all researches to estimate the stresses at the contact interfaces [3]. Mindlin [5] gave a solution for sliding contact wherein he assumed that the shear stress at contact surfaces is proportional to normal stress and proportionality constant is same as the co-efficient of friction between two interacting faces. Archard [6] tried to verify the Amontons's law considering the elastic deformation of surface asperities. Though elastic deformation of a single asperity does not explain the Amontons's law, in case of confirming surfaces the elastic deformation of many asperities does explain the Amontons's law. 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 tribological behavior 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. Theng- ShengYang [18] developed a new model to predict the surface roughness of product under lubricated condition. This model predicted the surface more accurately in case of lubricated sheet metal forming. Rigney and Hirth [19] developed a model to identify the source of friction in case of steady sliding. This model is based on plastic deformation at near surface. The model predicted well on the dependence of friction on load, sliding distance, surface temperature and micro structure. Suh and Sin [20] made attempt to explain friction with new theory; this theory was taken into account of sliding distance and environment. The theory suggested that the compatibility of sliding surface is dictated by mechanical properties like hardness than relative solubility.

II. EXPERIMENTAL PROCEDURE

Lead, copper, and aluminum (Al 6082), which are soft in comparison to the tougher mild steel (EN8), are machined into the shape of a pin, as seen in figure 1. Figure 2 depicts the dimensions of a plate machined from EN8 steel. All dimensions are in mm.

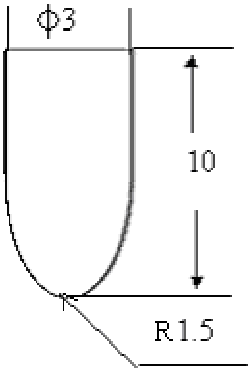

Fig.1. Dimensions of pin

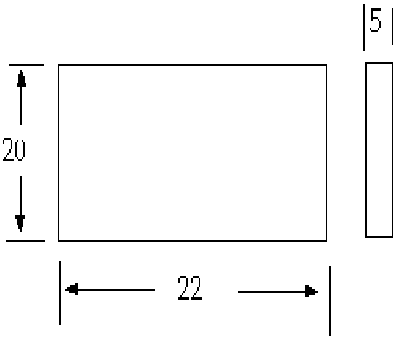

Fig. 2.Dimensions of Mild Steel (EN8) Plate

The EN8 flat surfaces were adjusted using three production processes: grinding (Silicon Carbide wheel polishing), sandblasting, and electric discharge machining (EDM). The surface of such changed plates was investigated using a non-contact three-dimensional optical profilometer. The average surface roughness metric, Ra, was measured and recorded for each surface. Figure 3 depicts the three-dimensional surface contour of flat.

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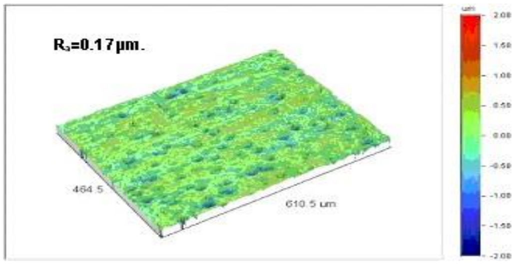


Fig.3 (a): The three dimensional view of ground (SiCwheel polished) plate surface.

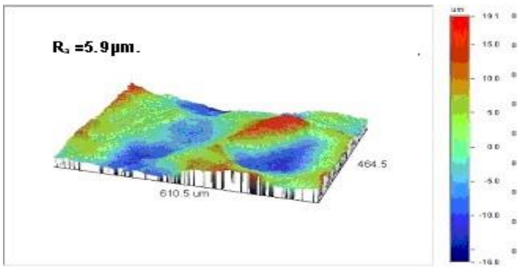


Fig.3 (b): The three dimensional view of shot blast platesurface

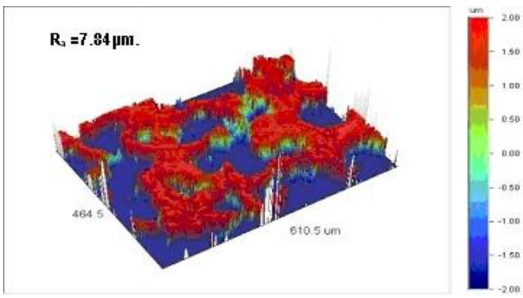


Fig.3(c): The three-dimensional view of EDM plate surface.

The average surface roughness value R_a 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 R_a of ground (Silicon Carbide wheel polished) surface was minimum and R_a 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.

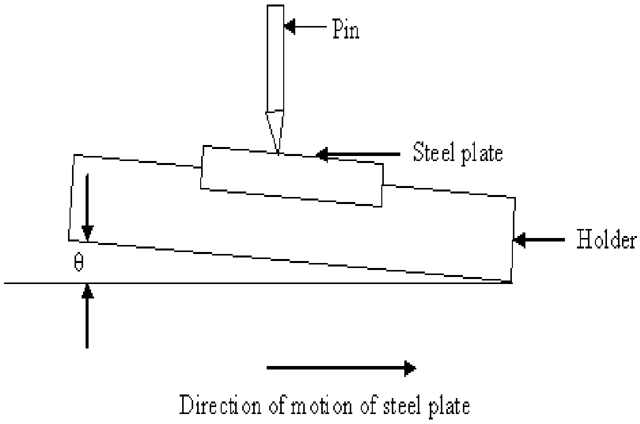


Fig .4: Schematic diagram of Pin on Plate with Inclinedsteel plate.

The cleaned pins were slid at a velocity against the cleaned lubricated EN8 steel plates from lower end to the higher endof 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

Experiments were conducted for different parameters under lubricated condition. The parameters were surface roughness (R_a), hardness of pin and plate inclination angle (θ). Pins used were lead, copper and aluminum. The surface roughness was characterized by R_a. 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 degrees 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.

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.

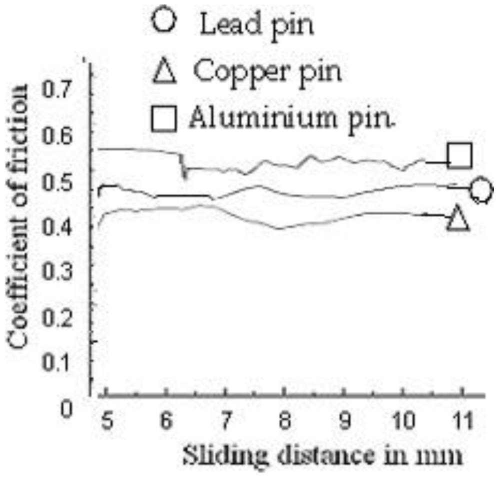


Fig. 5: Dependency of co-efficient of friction with slidingdistance for ground (SiC polished) steel surface.

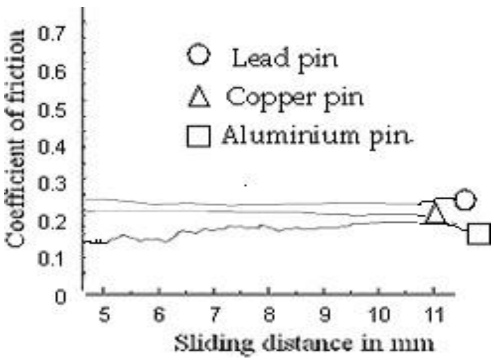


Fig. 6: Dependency of co-efficient of friction with slidingdistance for shot blast steel surface.

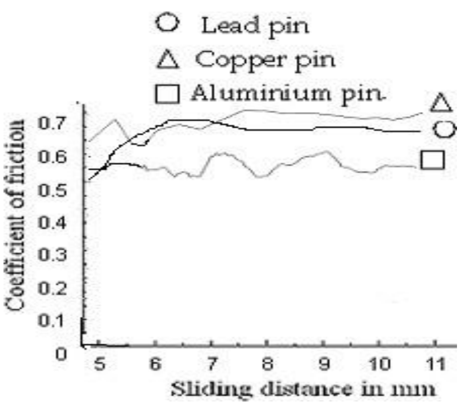


Fig.7: Dependency of co-efficient of friction with slidingdistance for EDM surface

The graphs shown in fig.5, Fig.6 and Fig.7 show the dependency of co-efficient of friction on sliding distance. The co-efficient of friction was found to be steady with sliding distance. The co-efficient of friction for lead is found to be more when compared to copper and aluminum pins for ground (SiC wheel polished) surface. In case of shot blast surface the aluminum pin was found to have maximum co-efficient of friction instead of lead and copper pin. In case of EDM surface the co-efficient of friction for copper pin is maximum. Further the co-efficient of friction is found to increase with R_a 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 in presence of lubrication. 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 aluminum pins were slid against ground (silicon carbide polished), shot blast and electric discharge machined steel surfaces. The curves with open symbols represent the lubricated sliding.

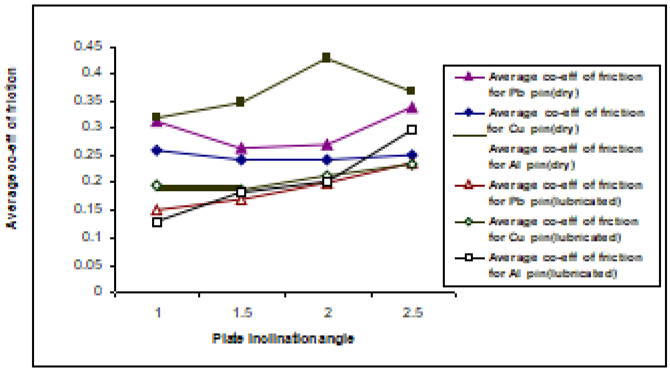


Fig. 8(a): The dependence of Average co-efficient of friction with plate inclination angle when Pb, Cu and Alpins slid on ground (SiC) steel surfaces.

(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 aluminum pin at an inclination angle of one degree. The co-efficient of friction value under identical condition was found to be less for lubricated sliding compared to dry sliding.

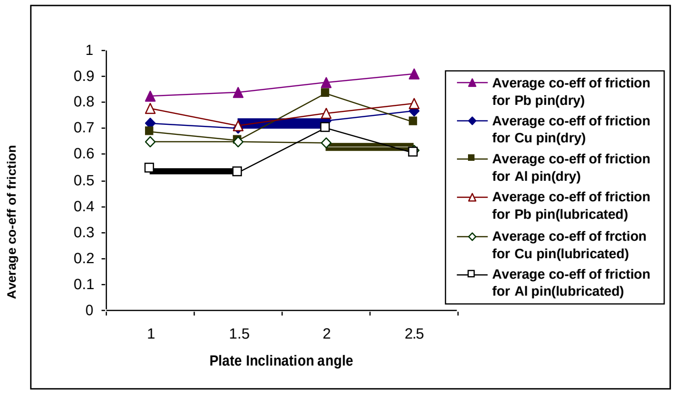
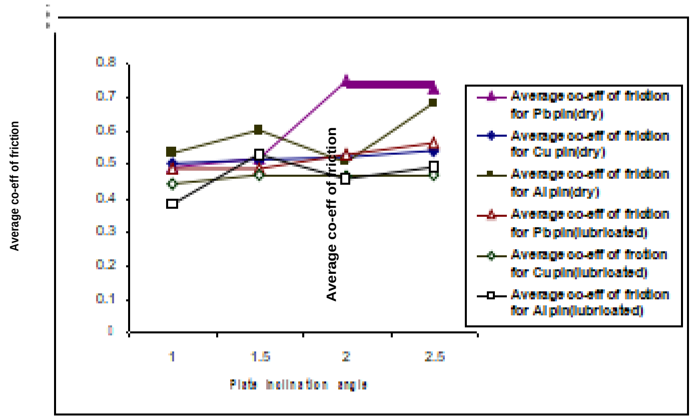


Fig. 8(b): The dependence of Average co-efficient of friction with plate inclination angle when Pb, Cu and Alpins slid on shot blast steel surfaces

Figure8(c) shows that co-efficient of friction values for lead and copper was found to be independent of plate inclination angle, whereas there was marginal increase in friction value for aluminum pin. The friction value for lubrication condition like in other two surfaces was found to be less compared to dry sliding. The average co-efficient of friction for lead, copper and Aluminum 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).

The average co-efficient of friction for aluminum pins slid on ground (SiC) steel surfaces under lubricated condition was found to be independent of plate inclination angle. Whereas in case of copper and lead pins the co-efficient of friction under identical condition was found always smaller for lubricated surface compared to dry surface. Under lubricated condition, in general, the co- efficient of friction was found to be independent of plate inclination angle.



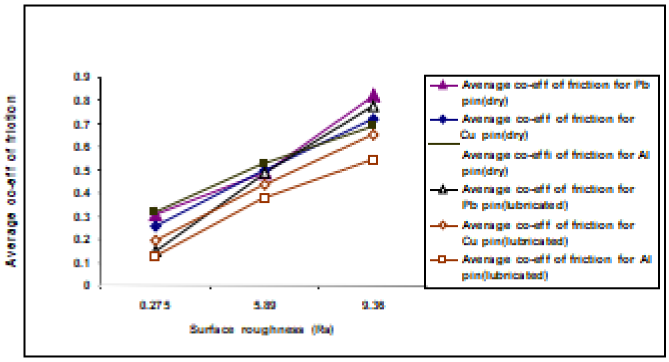


Fig. 8(c): The dependence of Average co-efficient of friction with plate inclination angle when Pb, Cu and Al pins slid on electric discharge machined steel surfaces.

IV. CONCLUSIONS

The impact of hardness is studied by moving lead, copper, and aluminium (Al6082) pins across steel plates. The trials used three distinct inclination angles: one degree, two degrees, and three and a half degrees. A standard load ranging from 1 to 150 N was used for the testing. In preparation for the trials, the surrounding circumstances were made lubricant. We used a scanning electron microscope to look at the process of depositing transfer layers onto plate and pin surfaces. Evidence suggests that the hard surface's shape influences the friction coefficient and the development of transfer layers under lubricated conditions. There seems to be a negative correlation between surface roughness and the amount of transfer layer production. Under lubricated circumstances, the connection between the coefficient of friction and sliding distance proved that sliding is stable. There was no discernible change in the average lubricated coefficient of friction when the angle of plate tilt changed. Surface roughness (Ra) was shown to enhance the average coefficient of friction under lubricated circumstances. The coefficient of friction was shown to rise with the introduction of transfer layers. Under lubricated conditions, the quantum of the transfer layer increased as the coefficient of friction did. In lubricated conditions, the average coefficient of friction is lower than in dry conditions.

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