ROLE OF SURFACE TEXTURE ON FRICTION AND TRANSFER LAYER FORMATION DURING SLIDING OF PVC PIN ON STEEL PLATE

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ABSTRACT
In the present investigation, sliding experiments were conducted using an inclined pin-on-plate apparatus to identify the role of surface texture on coefficient of friction and transfer layer formation of polymeric materials. In the experiments, poly vinyl chloride (PVC) was used for the pin and hardened steel was used for the plate. Two surface parameters of the steel plates – roughness and texture – were varied in the experiments. Experiments were conducted under both dry and lubricated conditions in an ambient environment. Based on the experimental results, it was observed that the transfer layer formation and the friction magnitude were controlled by the surface texture. The polymer material results were then compared with results for soft metallic pins. These comparisons showed that polymers and soft metals exhibit similar frictional responses, but the metal materials had a significantly larger variation in friction with surface texture.

INTRODUCTION
Polymers are the most common engineering materials used in consumer products and structural applications. The tribological characteristics of polymers are influenced by temperature, relative speed of the interacting surfaces, normal load, surface texture and environmental conditions. The majority of polymeric components are manufactured by injection molding techniques. During molding, friction forces develop between the polymer surface and the surface of the mold, which is usually made of hardened die steel. Thus, knowledge of the friction properties of the mating metal and plastics surfaces are important for optimizing polymer processing techniques.

In the present investigation, efforts were made to specifically study the tribological interaction between a polymer and a hardened steel surface. Among the factors that influence friction, the role of surface texture was primarily considered. In the literature, it is reported that the surface texture plays an important role in friction [1, 2] under sliding conditions. A few investigators made an attempt to study the effect of surface texture of polymeric materials on friction [3, 4]. The surface texture of deformable polymeric materials, however, is not important when considering sliding contact with hard metal materials such as steel because the polymer texture is quickly removed during sliding. Under these conditions, it is more important to have knowledge of the surface texture of the harder material which does not significant wear over time.

EXPERIMENTAL DETAILS
In the experiments, the pins were made of poly vinyl chloride (PVC). The counter-part, plate was made of H-11 die steel. To prepare the samples for the experiments, the steel plates were ground to attain three different surface textures - unidirectional, 8-ground, and random. The unidirectional and 8-ground surfaces were created by dry grinding the plates with emery papers of 220, 400, 600, 800 or 1000 grit sizes. For the unidirectional case, care was taken so that the grinding marks were unidirectional in nature. The 8-ground surface was generated by moving the steel plate against dry emery papers along a path with the shape of an “8” for 500 cycles. The random surface with varying roughness was generated under wet grinding conditions using a polishing wheel and one of three abrasive media: SiC powder (220, 600 and 1000 grit), Al2O3 powder (0.017 µm), and diamond paste (1-3 µm).

Experiments were conducted using a pin-on-plate sliding test apparatus [2]. The apparatus is robust in that the effect of load on the coefficient of friction can be readily determined in a single experiment. To perform the experiments, the steel plate was fixed horizontally in the vice of the pin-on-plate sliding tester and then the vice setup was tilted so that surface of the plate made an angle of 1° ± 0.1° with respect to horizontal base.

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Then pins were slid at a speed of 2 mm/s against the prepared steel plate starting from the lower end to the higher end of the inclined surface for a sliding length of 10 mm. The normal load was varied from 1 to 120 N during the tests. The pins were slid both in perpendicular and parallel direction to the unidirectional grinding marks on the plate. Thus, four sets of experimental conditions were used. Experiments were conducted under both dry and lubricated conditions on each plate in an ambient environment. Surface roughness parameters of the steel plate were measured in the direction of the sliding on the bare surface away from the sliding tracks using an optical profilometer. Scanning electron micrographs of the contact surfaces of pins and plates were obtained to reveal the morphology of the transfer layer.

RESULTS AND DISCUSSION

It was observed that the coefficient of friction did not vary significantly for normal loads up to 120N. Variation of average coefficient of friction with surfaces texture when PVC pins were slid on steel plates of varying roughness under both dry and lubricated conditions is shown in Fig. 1. In the figure, UPD and UPL represent the test conditions where sliding is respectively perpendicular and parallel to the unidirectional grinding marks. The error bars in the figure indicate the maximum and minimum values of the friction and surface roughness ($R_a$) of a particular surface texture. Each symbol on Fig. 1 is the average coefficient of friction of five roughness of the same texture. As indicated in the figure, the range of surface roughness, $R_a$, varies between 0.02 and 0.38 µm for the different textured surfaces examined. For a given texture, the average coefficient of friction did not substantially vary over this range of roughness. From Fig. 1, it can be noticed that the coefficient of friction depends considerably on the surface texture under both dry and lubricated conditions. Under dry condition, the coefficient of friction values are much higher when compared to the lubricated conditions. It can be observed that the coefficient of friction for the dry experiments is highest when sliding perpendicular to the unidirectional grinding marks (UPD), followed by the 8-ground, then the parallel to the unidirectional grinding marks (UPL), and finally the randomly polished surfaces. A similar trend is seen for the lubricated experiments.

Fig. 2 shows the backscattered SEM images of different textured steel plates that slid against PVC pins under dry conditions. Under both dry and lubricated conditions, it was noticed that the amount of transfer layer formed on the steel plate surface was highest for the UPD case and progressively decreased for the 8-ground, UPL, and randomly polished steel plates. It was observed that the amount of transfer layer formed on the steel plate was larger under dry conditions than that of under lubricated conditions. It can also be found under both dry and lubricated conditions that the amount of the transfer layer formed on the steel plate did not significantly vary with surface roughness. SEM images of the PVC pins slid on various surface textures under dry conditions showed surface shearing on the pin surfaces. Under lubricated conditions, the intensity of surface shearing was significantly reduced.

Experiments were conducted under identical testing conditions using soft metallic pins made from pure Zn and Al-4Mg alloy. Friction coefficient result comparisons were then made between the PVC and metallic pins in Fig. 3 as a function of surface texture. Each data point on the Fig. 3 refers to the average coefficient of friction of five roughness of the same texture. Figure 3 shows that both polymer and metals exhibited similar frictional response with surface texture. A much large variation in friction with surface texture is observed for the metals compared to the polymers.
It has been well established that there are two main non-interacting components of friction - adhesion and plowing. To understand the polymer friction results studied in this work, it is important to determine the relative contribution of each component under different conditions. The contribution of the adhesion component can be reduced by introducing a lubricant at the interface between contacting surfaces. Based on our previous analysis [2], it was determined that the coefficient of friction recorded for the lubricated experiments were in the boundary lubrication regime and included plowing components of friction. Examining Fig. 1, it is found that plowing (friction values under lubricated conditions) is the dominant friction mechanisms as its value is significantly greater than the adhesive component (which is the difference between coefficient of friction values for the dry and lubricated experiments). Specifically examining the plowing component, Fig. 1 indicates that the plowing friction is highest for UPD case and steadily decreases for 8-ground, UPL and random surfaces. However, the adhesion component does not significantly vary with surface texture. Because the plowing component is dominant and considerably varies with surface texture, it can be inferred that the variations in total friction are primarily due to changes in plowing behavior.

Considering the present set of experiments involving UPD tests, a representative model of a single asperity can be used to describe the physical phenomena involved. More specifically, the interaction can be represented by a softer material flowing over the asperities. In such a process, the constraint to flow of the polymeric material increases. Such a situation induces a higher level of shear stresses leading to severe shear failure and higher material transfer. This also increases the plowing component of friction. In the UPL case, the softer material did not climb over the asperities, and instead it flowed along the valleys of the steel plate which requires less energy for the deformation. Thus, the level of stresses and the plowing component generated in UPL tests were lower than those in the UPD tests. For 8-ground surface, the softer pin meets the asperities of the steel plate that are aligned in many orientations. Thus, one can expect generation of moderate shear stresses, and corresponding modest plowing components of friction. For the random surfaces, the coefficient of friction is lower as the flow is unconstrained and moves within the unidirectional grooves. This causes lower stresses, lower plowing friction, and lower amounts of material transfer.

CONCLUSIONS

- The coefficient of friction is controlled by the surface texture of harder counter surface
- The contribution of plowing component to the total coefficient is the key factor.
- The transfer layer depends on coefficient of friction which in-turn depends on the texture of harder counter surface.
- Both polymer and metals exhibited similar frictional response with surface texture.

REFERENCES