INFLUENCE OF TILT ANGLE OF PLATE ON FRICTION AND TRANSFER LAYER – A STUDY OF ALUMINUM PIN SLIDING AGAINST STEEL PLATE

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ABSTRACT

In the present investigation, basic studies were conducted using an inclined pin-on-plate sliding tester to understand the influence of tilt angle and grinding marks direction of the plate on coefficient of friction and transfer layer formation during sliding against soft aluminium (Al) pin. 080 M40 steel plates were ground to attain different surface roughness with unidirectional grinding marks. Then Al pins were slid at 0.2°, 0.6°, 1.0°, 1.4°, 1.8°, 2.2° and 2.6° tilt angles of the plate with the grinding marks perpendicular and parallel to the sliding direction under both dry and lubricated conditions. Scanning Electron Microscopy was used to study the morphology of the transfer layer formed on the plates. Surface roughness of the plate was measured using an optical profilometer. It was observed that the transfer layer formation and the coefficient of friction depend primarily on the grinding marks direction of the harder mating surface. Stick-slip phenomenon was observed only under lubricated conditions. For the case of pins slid perpendicular to the unidirectional grinding marks stick-slip phenomenon was observed for tilt angles exceeding 0.6°, the amplitude of which increases with increasing tilt angles. However, for the case of the pins slid parallel to the unidirectional grinding marks the stick-slip phenomena was observed for angles exceeding 2.2°, the amplitude of which also increases with increasing tilt angle. The presence of stick-slip phenomena under lubricated conditions could be attributed to the molecular deformation of the lubricant component confined between asperities.

INTRODUCTION

Friction is the force resisting the relative motion of two surfaces in contact. The important factors that control friction are the surface texture, normal load, sliding speed, temperature, lubricants, and the material properties [1].

The present study focuses on the effect of surface texture of the harder material on coefficient of friction during sliding. In literature a few authors accounted the role of surface texture of harder material on friction. Staph et al. [2] pointed out that both surface texture and surface roughness affect frictional behavior. Also, Menezes et al. [3] reported that the coefficient of friction is controlled by the surface texture of harder counter surface. In addition, Menezes et al. [4] accounted that the coefficient of friction and transfer layer formation depend on the directionality of the grinding marks of the harder mating surface.

EXPERIMENTAL DETAILS

Surface textures with varying roughness were produced on 080 M40 steel plates by dry grinding the steel plates against emery papers of 220, 400, 600, 800 or 1000 grit sizes. Care was taken so that the grinding marks were unidirectional in nature. The roughness profiles of the steel plates were taken using an optical profilometer. Figure 1 shows the three-dimensional surface profiles of as-ground steel plate with unidirectional grinding marks.

![Fig. 1: 3D profile of unidirectionally ground steel plate.](image)

The pins were made of super purity Al (99.997 wt. %). The pins were 10 mm long, 3 mm in diameter with a tip radius of 1.5 mm. The dimensions of the 080 M40 steel plates were 28 mm x 20 mm x 10 mm (thickness). Experiments were done using an inclined pin-on-plate sliding tester [5]. The effectiveness of this test is that from a single experiment the influence of normal load on coefficient of friction can be studied. The steel plate was fixed horizontally in the vice of the pin-on-plate sliding tester and then vice setup was tilted so that surface of the plate makes an angle of 0.2° ± 0.05° with respect to horizontal base. Then pins were slid at a speed of 2 mm/s against the prepared steel plate starting from lower end to the higher end of the
inclined surface for a sliding length of 10 mm. Normal load varied from 1 to 30 N during the test. The experiments were done for both perpendicular and parallel to the unidirectional grinding marks. Similar experiments were conducted for 0.6°, 1.0°, 1.4°, 1.8°, 2.2° and 2.6° tilt angles of the plate with the grinding marks perpendicular and parallel to the sliding direction. For 2.6° tilt angle, the normal load varied from 1N to 230 N during the test. For a given tilt angle and a given grinding marks direction, the tests were conducted for five surface roughness generated using various grit size emery papers. Experiments were conducted under both dry and lubricated conditions on each plate in ambient environment. The dry tests were conducted first followed by the lubricated ones, to avoid any additional cleaning of the steel plates and to exclude variations in roughness of the steel plates. For the lubricated tests, a drop (i.e., 0.05 ml) of commercially available engine oil lubricant (SAE 40, API rating SJ class) was applied on the surface of the same steel plate. The profiles and surface roughness of the steel plates were measured in the direction of sliding on the bare surface away from the wear tracks using an optical profilometer. After the tests, the pins and steel plates were observed using a scanning electron microscope (SEM) to study the morphology of the transfer layer.

RESULTS & DISCUSSION

Figure 1 shows the variation of coefficient of friction with sliding distance when Al pins slid against steel plates of different tilt angles under both dry and lubricated conditions. Here, the sliding direction is perpendicular to the unidirectional grinding marks which is generated using 400 grits emery papers.

It can be seen that the coefficient of friction does not vary much with sliding distance. For a given tilt angle, the coefficient of friction did not vary much with surface roughness. In addition, under dry conditions, stick-slip phenomenon (oscillation in the coefficient of friction with sliding distance) was absent for all tilt angles. However, under lubricated conditions, stick-slip phenomenon was observed at higher loads. Further, it can be seen that the existence of stick-slip phenomenon and its amplitude depends on the tilt angles. It was observed that amplitude of oscillations starts at angles exceeding 0.6°, the amplitude of which increases with increasing tilt angle.

Figure 2 shows the variation of coefficient of friction with sliding distance when super purity Al pins slide against steel plates of different tilt angles under (a) dry and (b) lubricated conditions. Sliding direction is parallel to the unidirectional grinding marks.

The range of coefficient of friction values obtained under both the dry and lubricated conditions, for the various tilt angles are presented in figure 3. The error bar in the figure indicates the maximum and minimum values of average coefficient of friction for five surface roughness ($R_\alpha$) whereas the connecting line pertains to the average coefficient of friction for different tilt angles. Here unidirectional perpendicular (abbreviated UPD) represents sliding direction perpendicular to the unidirectional grinding marks, whereas unidirectional parallel (abbreviated UPL) represents sliding direction parallel to the unidirectional grinding marks. It was observed that the range of surface roughness, $R_\alpha$, varies between 0.1 and 1.0 µm for different tilt angles. From figure 3, it can be observed that the coefficient of friction varies considerably with tilt angles under both dry and lubricated conditions. It can also be observed under lubricated conditions that the coefficient of friction of UPD is always greater than that of UPL.

Figure 4 shows the SEM of the plates at 0.2° and 2.2° tilt angles for UPD and UPL cases under dry conditions. It was observed that for a given tilt angle, the amount of transfer layer formed on the plates
depends on the coefficient of friction. In addition, the transfer layer formation on the plate increases with increasing tilt angles. It was observed that the amount of transfer layer formed on the plates decrease with the application of lubricant. SEM of the pins tested under dry conditions for all tilt angles showed strong surface shearing and plowing and contacts. Thus, the level of stresses and the asperities, and instead it flowed along the valleys of surfaces have “wave” like texture. Thus, in the U-PD case, the softer pin material did not climb over the asperities. This stimulates a higher level of stresses leading to severe shear failure and higher amount of material transfer. The higher level of stresses also leads to higher plowing component of friction. In the U-PL 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 U-PL tests were lower than those in the U-PD tests.

For the U-PD case, at the asperity level, the condition involves plane strain during sliding and the lubricant present at the interface gets compressed, which increases in viscosity, leading to stick-slip motion. As explained earlier, the extent of plane strain conditions would be more for U-PD case and less for the U-PL case. Thus, the amplitude of oscillation would be more for the U-PD, and less for the U-PL owing to the extent of plane strain conditions. It was observed that the normal load required to initiate stick-slip motion increases as the tilt angle decreases. Higher loads are required to compress the lubricant at lower tilt angles and thus stick-slip motion occurs at higher loads. The existence of stick-slip phenomenon under lubricated conditions has also been reported by some authors [6-9].

CONCLUSIONS

- The coefficient of friction depends on the grinding marks direction of harder counter surface.
- Stick-slip phenomenon was observed under lubricated condition.
- The amplitude of stick-slip motion depends on the tilt angle.
- Stick-slip phenomenon depends on both grinding marks direction and tilt angle.

REFERENCES