**Proceedings of the STLE 2011 Annual Meeting & Exhibition**
**STLE2011**
**May, 15-19, 2011, Atlanta, Georgia, USA**

# STLE2011- 1005412

# ROLE OF SURFACE TEXTURE ON FRICTION AND TRANSFER LAYER FORMATION WHEN PURE ALUMINUM PINS SLID AT VARIOUS NUMBERS OF CYCLES ON STEEL PLATES

Pradeep L. Menezes[1, 3*†], Kishore[1], Satish V. Kailas[2] and Michael R. Lovell[3]

[1]Department of Materials Engineering, Indian Institute of Science, Bangalore 560 012, India
[2]Department of Mechanical Engineering, Indian Institute of Science, Bangalore 560 012, India
[3]Department of Industrial Engineering, University of Wisconsin-Milwaukee, Milwaukee, WI 53201, USA

## ABSTRACT

In the present investigation, various kinds of textures, namely, *unidirectional*, *8-ground*, and *random* were attained on the die surfaces. Pins made of aluminum were then slid against steel plates for various numbers of cycles using a pin-on-plate reciprocating sliding tester. It was observed that the friction and transfer layer formation depended on the die surface textures. Under lubricated conditions, the friction decreased for *unidirectional* and *8-ground* surfaces but increased for *random* surfaces as a function of cycles. Under dry conditions, the friction increased with increasing number of cycles for all kinds of surfaces. In the tests, the friction was always highest when sliding was perpendicular to the unidirectional textures and was lowest for the random textures under both dry and lubricated conditions. The difference in friction values between these two surfaces decreased with increasing number of cycles. The variation in the friction was attributed to the change in texture of the surfaces during sliding.

## INTRODUCTION

In metal forming processes, friction between the workpiece material and the forming tool play an important role because of their influence on the process performance and on the final product properties. In forming processes, the dies are hardened and non-deformable. Hence, the texture of the die surface is one of the critical parameters that control the frictional behavior at the contact interface.

Considerable efforts have been made to study the influence of die surface texture on friction during metal forming [1-4]. It is important to note that all these studies were confined to a single operation. However, in metal forming processes, the dies can be used for multiple operations. The surface texture of the die, therefore, might be changed substantially due to previous operations. To better understand this phenomenon, efforts were made to simulate the friction and wear that are encountered in the metal forming operations by means of simple laboratory sliding tests. More specifically, soft aluminum pins were slid against hard steel plates of different textures and roughness for different number of cycles using a pin-on-plate reciprocating sliding tester.

## EXPERIMENTAL DETAILS

In the experiments, the pins were made of high purity aluminum (99.997 wt. %). The counter-part, plate was made of H-11 die steel. To prepare the samples for the experiments, three kinds of surface textures were produced on the die steel. The *unidirectional* and *8-ground* surfaces with varying roughness 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 emery papers along a path with the shape of an “8” for about 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 or 1000 grit), $Al_2O_3$ powder (0.017 μm), or diamond paste (1-3 μm).

Experiments were performed using a pin-on-plate reciprocating sliding test apparatus. In the experiments, a constant normal load of 35 N was applied. The pins were slid at a velocity of 2 mm/s against the prepared steel plate for a track length of 10 mm in the forward direction (first half cycle) and then backward direction (another half cycle) to the initial position for each sliding cycle. Experiments were conducted under both dry and lubricated conditions on each plate in an ambient environment. Under dry conditions five parallel wear tracks were obtained on the same steel plate. Each wear track was produced by different number of reciprocating sliding

*Current address – Department of Industrial Engineering, University of Wisconsin-Milwaukee, Milwaukee, WI 53201
† Corresponding author – menezesp@uwm.edu Tel: (414) 229-3377

cycles such as 1, 3, 5, 10 and 20. A single pin was used for all the five sliding cycles. For the lubricated tests, a drop of commercially available engine oil lubricant was applied to the surface of the same steel plate and the tests were performed with a new aluminum pin to obtain another five parallel wear tracks of different number of reciprocating sliding cycles similar to the dry tests. Both the dry and lubricated tests were done on the same steel plate so that the results of the dry and lubricated experiments would exclude variations during preparation of the steel plates. The pins were slid both in perpendicular and parallel direction to the unidirectional grinding marks on the plate. Thus, four sets of topographic conditions were examined. Surface roughness parameters of the steel plate were measured using an optical profilometer. Scanning electron microscope was used to reveal the morphology of the transfer layer formed on the steel plates.

## RESULTS AND DISCUSSION

Figures 1 (a) and (b) present the range in which the coefficient of friction values fall for different roughness when the aluminum pin slid on different surface textures at different number of cycles under dry and lubricated conditions. In Fig. 1, UPD and UPL respectively represent the testing conditions where the sliding is perpendicular and parallel to the unidirectional grinding marks. The range of surface roughness, $R_a$, was varied between 0.1 and 0.6 μm for different textured surfaces. For a given surface texture, the average coefficient of friction did not substantially vary over this range of roughness. The error bars in the figure indicate the maximum and minimum values of the friction obtained for five roughness of a particular surface texture for a particular number of cycles. Each symbol on Fig. 1 refers to the average coefficient of friction of five roughness of the same texture. It can be observed that the coefficient of friction increases with increasing number of cycles under dry conditions for all kinds of textures. Under lubricated conditions, the coefficient of friction decreases for UPD, 8-ground and UPL surfaces as a function of cycles. The randomly ground surfaces, in contrast, show an increase in friction with the number of cycles. Under dry condition, the coefficient of friction values are much higher when compared to that under lubricated conditions. It can also be observed that the coefficient of friction depends significantly on the die surface textures during the first few cycles. The friction was highest for the UPD case, followed by the 8-ground, UPL case, and was the least for the randomly polished surfaces for the first few cycles. The difference in friction values among these surfaces decreases with increasing number of cycles.

Figure 2 (a) and (b) show backscattered scanning electron micrograph (SEM) of the steel plate tested under dry conditions when aluminum pin slid on UPD surfaces for 1st and 20th cycles, respectively. A significant amount of aluminum was transferred to the steel plates for the 1st cycle. It was found that the amount of transfer layer formed on the steel plate increased with increasing number of cycles. For the 20th cycle, the transfer layer completely covered the wear track and original surface texture was not observed under SEM as shown in Fig 2(b). Figure 3 (a) and (b) show backscattered SEM of the UPD surfaces tested under lubricated conditions for 1st and 20th cycles, respectively. It can be observed that the original grinding marks were wiped out during sliding and new grinding marks parallel to the sliding direction formed on the steel plate surface. The intensity of formation of new grinding marks parallel to the sliding direction increased with increasing number of cycles. It was found that the amount of transfer layer formed on the steel plate was larger under dry conditions than under lubricated conditions. Similar observations were noticed for other surfaces.

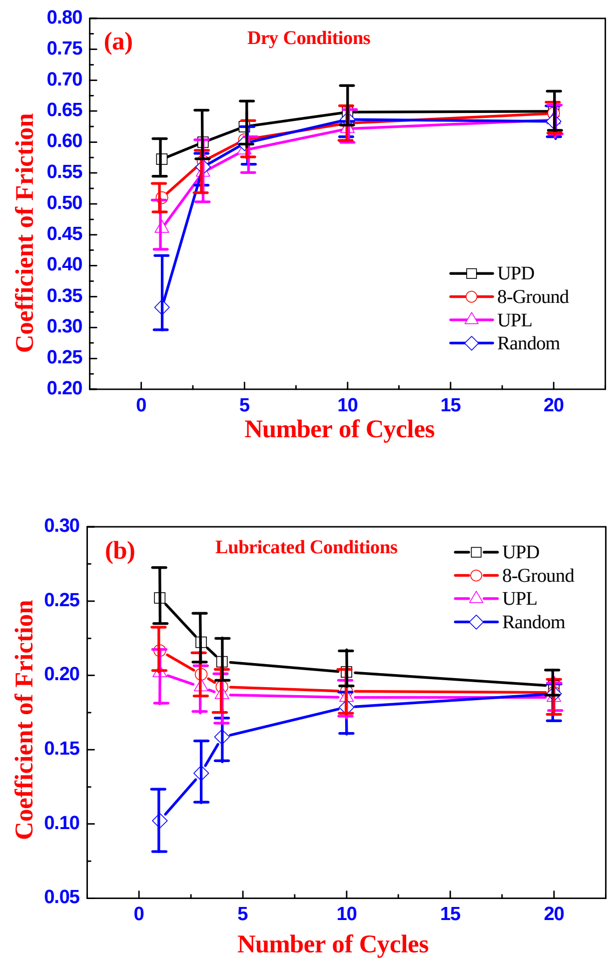


Fig. 1: Variation of average coefficient of friction with number of cycles for different surface textures under (a) dry and (b) lubricated conditions.

Previous efforts [3, 4] have shown that the higher coefficient of friction for the UPD case was attributed to the constrained nature of flow for the softer aluminum pin material during sliding. For the case of random surfaces, the coefficient of friction was lower as the flow was unconstrained and provided less resistance to the aluminum pin during sliding. The constraint to flow offered by the 8-ground and UPL surfaces was expected to fall in between the UPD and the random surfaces [3, 4].

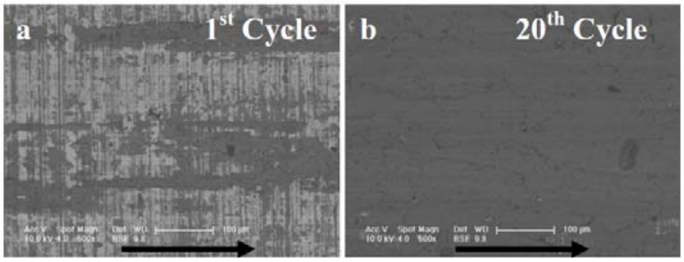


Fig. 2: Backscattered SEM of UPD surfaces tested under dry conditions for (a) 1st and (b) 20th cycles. Arrows indicated the sliding direction of the pin relative to the plate.

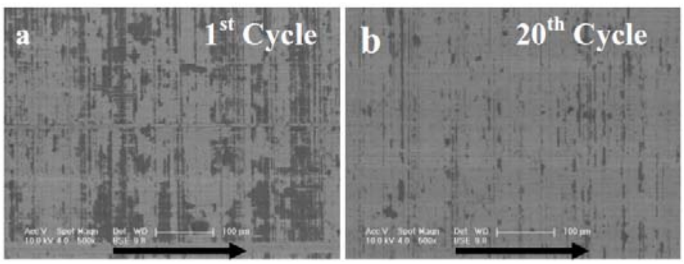


Fig. 3: Backscattered SEM of UPD surfaces tested under lubricated conditions for (a) 1st and (b) 20th cycles. Arrows indicated the sliding direction of the pin relative to the plate.

Under dry testing conditions, the coefficient of friction was found to increase with increasing number of cycles. It was also observed that the transfer layer formation increased with increasing number of cycles. The formation of transfer layer on the plate during each cycles leads to sliding against similar pairs and thus the adhesion component of friction [3] increases with increasing number of cycles. In addition, each sliding cycle work-hardens the contacting interface. The work-hardened transfer layer acts as third-body abrasive during sliding. Hence, both coefficient of friction and transfer layer increases with increasing number of cycles. Under lubricated condition, the amount of transfer layer formation significantly less. So, the sliding condition produces work-hardening of the pin material and the rate of work-hardening in the pin increases with increasing number of sliding cycles. Thus, one would expect an increase in surface hardness of the pin material with increasing number of cycles. This leads to damage to the plate material and creation of new unidirectional grinding marks on the plate along the sliding direction. The probability of creation of new unidirectional grinding marks along the sliding direction increases with increasing number of cycles. Thus, after a critical number of cycles, the sliding condition is akin to the UPL case. This phenomenon is highlighted by the fact that the friction change is lowest for the UPL lubricated experiments (Fig. 1(b)). The coefficient of friction during the 1st cycle for the random case under lubricated condition is less than that of the UPL case. As the cycle number increases, new unidirectional grinding marks parallel to the sliding direction form due to work hardening of the pin material. The sliding condition behaves similar to the UPL case and thus the friction coefficient increases with number of cycles.

## CONCLUSIONS

- The coefficient of friction and transfer layer formation under both dry and lubricated conditions during the first few cycles depended on the die surface textures. More specifically, for the first few cycle, the coefficient of friction is highest for the unidirectional surfaces with sliding direction is perpendicular to the unidirectional grinding marks (UPD) and decreases for the 8-ground surfaces and then the unidirectional surfaces with sliding direction is parallel to the unidirectional grinding marks (UPL), and lowest for the randomly polished plates. The difference in friction values among these surfaces decreases with increasing number of cycles.
- The coefficient of friction increased with number of cycles under dry conditions for all kinds of textures. This was attributed to increased adhesion with cycle number and work-hardening of the transfer layer which acted as third-body abrasive.
- Under lubricated conditions, the amount of transfer layer formation was less. The work hardening of the pin led to the creation of new grinding marks along the sliding direction. Thus, the coefficient of friction was akin to the UPL texture at the end of 20th cycles.
- The variation in the coefficient of friction under both dry and lubricated conditions is attributed to the change in texture of the surfaces during sliding.

## REFERENCES

[1] Lakshmipathy, R., and Sagar, R., 1992, “Effect of Die Surface Topography on Die-Work Interfacial Friction in Open Die Forging,” Int. J. Mach. Tools Manuf., **32**(5), pp. 685–693.

[2] Malayappan, S., and Narayanasamy, R., 2004, “An Experimental Analysis of Upset Forging of Aluminium Cylindrical Billets Considering the Dissimilar Frictional Conditions at Flat Die Surfaces,” Int. J. Adv. Manuf. Technol., **23**(9–10), pp. 636–643.

[3] Menezes, P. L., Kishore, and Kailas, S. V., 2006, “Studies on Friction and Transfer Layer: Role of Surface Texture,” *Tribol. Lett.*, **24**(3), pp. 265-273.

[4] Menezes, P. L., Kishore, and Kailas, S. V., 2009, Influence of Surface Texture and Roughness Parameters on Friction and Transfer Layer Formation during Sliding of Aluminium Pin on Steel Plate,” *Wear*, **267**(9-10), pp. 1534-1549.