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STUDIES ON FRICTION AND TRANSFER LAYER FORMATION WHEN HIGH PURITY ALUMINUM PINS SLID AT VARIOUS NUMBERS OF CYCLES ON STEEL PLATES OF DIFFERENT SURFACE TEXTURE

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ABSTRACT

In the present investigation, *unidirectional, 8-ground,* and r*andom* surface textures were attained on the steel plates. Using an inclined pin-on-plate testing system, high purity aluminum pins were then slid against the steel plates at various numbers of cycles. In the experiments, it was observed that the coefficient of friction and formation of transfer layer during the first few cycles depend on the surface textures under both dry and lubricated conditions. More specifically, the coefficient of friction decreases for *unidirectional* and *8-ground* surfaces while for *random* surfaces it increases with number of cycles. The variation in the coefficient of friction is attributed to the change in texture of surfaces during sliding. The change in texture is found to vary based on the initial texture of the plate.

INTRODUCTION

In sheet metal forming processes, the level of the friction plays a significant role in final part quality since friction directly influences the stress and strain distribution in the sheet. In most forming processes such as stamping, there is a general range for friction between components that lead to a sheet that has a desirable shape and surface quality. Thus, the stability of tribological conditions in metal forming operations will to a large extent influence the process productivity and ultimate value of the formed product. In sheet forming, friction between the tool and work-piece has a significant effect on the material deformation, forming load, component surface finish and die wear. It has been reported that surface texture of the die plays an important role in coefficient of friction during forming [1, 2]. By introducing specific textures on the die, the tribological properties between the sheet and die can be controlled to optimize the characteristics of the formed product.

Efforts have been made to study the influence of surface texture on friction and transfer layer formation during sliding conditions [3, 4]. These works were confined to a single sliding event. However, in metal forming processes, the dies can be used for multiple sliding events. The surface texture of the die, therefore, might be changed substantially due to previous sliding events where a transfer layer fills valleys between the asperities. To better understand this phenomenon, the present investigation simulates friction and wear in metal forming by sliding soft aluminum pins for multiple cycles against hard steel plates of different textures and roughness using an inclined pin-on-plate 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 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 dry 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 conducted using an inclined pin-on-plate sliding test apparatus [4]. 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-

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plate sliding tester and then the vice setup was tilted so that surface of the plate made an angle of $1^o \pm 0.1^o$ with respect to horizontal base. Pins were then slid at a velocity of 2 mm s^{-1} 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. Experiments were conducted under both dry and lubricated conditions on each plate in an ambient environment.

Under dry conditions experiments were conducted to obtain five parallel wear tracks on the same steel plate. Each wear track was produced by different number of sliding cycles such as 1, 2, 6, 10 and 20. Note that 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 sliding cycles. 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 used. Surface roughness parameters of the steel plate were measured using an optical profilometer. Scanning electron micrographs of the contact surfaces of pins and plates were observed to reveal the morphology of the transfer layer.

RESULTS AND DISCUSSION

It was observed that the coefficient of friction did not vary significantly as a function of normal loads up to 120 N. Figures 1 (a) and (b) present the range in which the coefficient of friction values fall for different roughness when aluminum pin slid on different surface textures at different number of cycles under dry and lubricated conditions. In Fig. 1, U-PD and U-PL 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 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 was observed under both dry and lubricated conditions that the coefficient of friction decreases for U-PD, 8-ground and U-PL surfaces as a function of cycles. The randomly surface conditions, 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 U-PD case, followed by the 8-ground, U-PL case, and was the least for the randomly polished surfaces for the first few cycles. At higher number of cycles, the friction was independent of die surface texture. An interesting point to note is that the coefficient of friction values converge, though to a lesser degree under lubricated conditions, to the U-PL surface value. A stick-slip phenomenon was observed only under lubricated conditions when pins slid perpendicular to the *unidirectional* texture. The amplitude of vibration induced by the stick-slip phenomenon increased with increasing number of cycles.

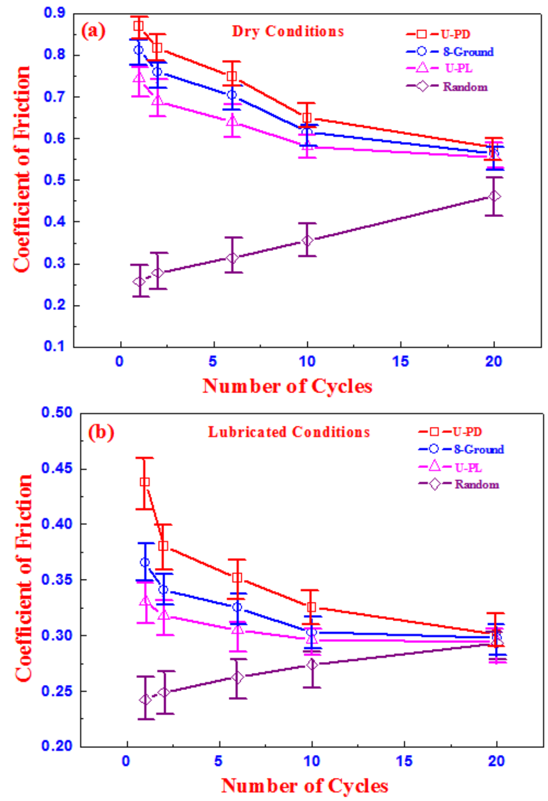

Fig. 1: Variation of average coefficient of friction with number of cycles for different surface textures under (a) dry and (b) lubricated conditions.

Figure 2 shows scanning electron micrographs of the different textured steel plates tested for the 1^{st} and 20^{th} cycles under dry conditions. A significant amount of aluminum was transferred to the steel plates under dry conditions. At lower magnification, it was found that the amount of transfer layer formed on the steel plate increased with increasing number of cycles up to 6^{th} cycle, and thereafter fragmentation of the transfer layer takes place. After the 6^{th} cycle, the original grinding marks were wiped out during sliding and new grinding marks parallel to the sliding direction formed on the steel plate surface. Similar observations were made under lubricated conditions. It was found that amount of transfer layer formed on the steel plate was larger under dry conditions than under lubricated conditions. The intensity of formation of new grinding marks parallel to the sliding direction was less under lubricated conditions when compared to that under dry conditions. It was seen that the amount of transfer layer formed on the steel plate increases with increasing normal load.

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Scanning electron micrographs of the aluminum pins slid on various surface textures under dry conditions showed surface shearing on the pin. Under lubricated conditions, the intensity of surface shearing was significantly reduced.

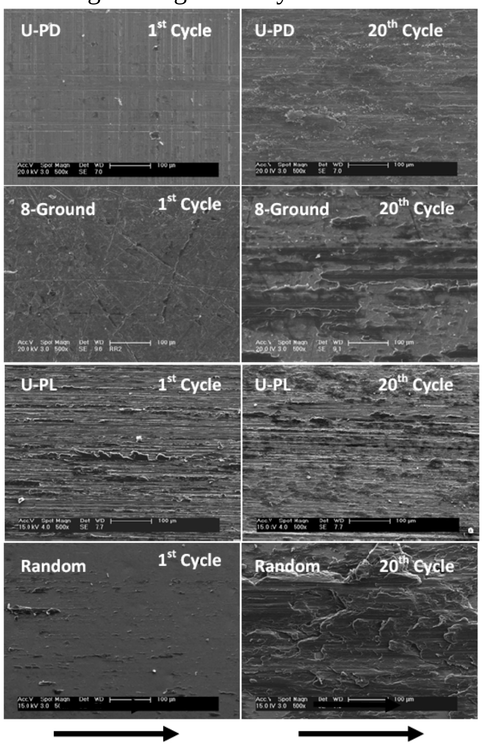

Fig. 2 SEM of different textured surfaces tested under dry conditions for 1st and 20th cycles. Arrows indicated the sliding direction of the pin relative to the plate.

Previous experiments have found [4] that the higher coefficient of friction for the U-PD case was attributed to the constrained nature of flow for the soft material. For the random surface case in this paper, the coefficient of friction was lower as the flow was unconstrained. The constraint to flow offered by the 8-ground and U-PL surfaces was expected to fall in between the U-PD and the random surfaces. When the pins slid parallel to the unidirectional grinding marks (U-PL case), the transfer layer continuously builds up with increasing number of cycles and accumulates between the asperities. This in turn decreases the difference in height between peaks to valleys of the asperities. Thus, the coefficient of friction decreases with number of cycles. When the pins slid on U-PD or 8-ground texture, new unidirectional grinding marks which are parallel to the sliding direction start to form. The intensity of formation of new grinding marks parallel to the sliding direction increases with increasing number of cycles. It is believed that the sliding condition produces work-hardening of the pin material and the rate of work-hardening increases with increasing number of sliding cycles. Thus, one would expect increases in surface hardness of the pin material with increasing number of cycles. This leads to damage to the plate material and the creation of new unidirectional grinding marks on the plate along the sliding direction. Thus, after a certain number of cycles, the sliding condition is akin to the U-PL case. The coefficient of friction during the 1st cycle for the random case is less than that of the U-PL case. As the number of cycles increases, new unidirectional grinding marks parallel to the sliding direction form. The sliding condition behaves similar to the U-PL case and thus the coefficient of friction increases with number of cycles. This change in roughness would play an important role in the change in the microstructure of the formed part [5] and will also change the tolerance of the formed sheet as the dies surface gets worn away.

CONCLUSIONS

- The coefficient of friction and formation of transfer layer under both dry and lubricated conditions during the first few cycles depend on the die surface textures. After a run-in period, friction becomes independent of the surface texture.
- The friction value levels off to the unidirectional parallel direction as the steel surface gets worn and develops a unidirectional parallel texture.
- The variation in the coefficient of friction is attributed to the change in texture of the surfaces rather than the roughness, R_a, of the surfaces during sliding.

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