Role of Surface Texture and Roughness on Friction and Transfer Film Formation when UHMWPE Sliding Against Steel

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Abstract—Understanding friction between material pairs is very crucial when utilizing the materials in various applications, including mechanical and biological systems. In the present investigation, efforts were made to study the influence of surface texture and roughness on friction and transfer film formation during sliding of Ultra High Molecular Weight Polyethylene (UHMWPE) pins against steel plates using an inclined pin-on-plate sliding tester. In the experiments, various kinds of surface textures, namely unidirectional, 8-ground, and random are considered. The roughness of the textures was quantified using optical profilometer. Scanning Electron Microscope was used to study the transfer film formation. It was found that the friction and transfer film formation significantly depends on surface texture when compared to surface roughness ($R_s$). The variations in friction with surface texture is attributed to the nature of constraints imposed by the surface textures at the asperity level during sliding condition.

Keywords—Surface Texture, Roughness, Friction, Transfer film, UHMWPE

I. INTRODUCTION

Friction is a very important parameter that governs the selection of contacting materials in mechanical and biological systems because it affects numerous variables including the stresses, working conditions and the transfer film/debris formation [1].

In the present investigation, the tribological properties of UHMWPE against steel was studied as a function of surface texture and roughness. In literature, several attempts were made to study the tribological properties of UHMWPE against steel under dry sliding and various lubricated conditions [2-4]. However, no attempts were specifically made to study influence of surface texture and roughness on the frictional behavior.

II. EXPERIMENTAL METHODS

In this study, three kinds of textures were produced on the steel plate surfaces. They are unidirectional, 8-ground and random. The unidirectional surfaces were prepared by grinding the plates against emery papers in a unidirectional fashion. 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. For the unidirectional and 8-ground surfaces, the roughness was varied using different grits of emery papers, such as 220, 400, 600, 800 and 1000. The random textures were generated on the steel plates by polishing the steel plate against the pad of a standard metallographic disc polishing machine. For the random surfaces, the roughness was varied using different abrasive powders, such as SiC powders (600 and 1000), alumina powder and diamond paste.

Experiments were conducted using a pin-on-plate inclined sliding tester [5]. In the experiments, the pins were made of UHMWPE and the counterpart plates were made of steel. The pins were slid at a sliding velocity of 2 mm/s against the prepared steel plate surfaces under dry condition on each plate in an ambient environment. The normal load was varied from 1 to 120 N during the tests. The pins were slid both in perpendicular (UPD) and parallel (UPL) direction to the unidirectional grinding marks on the plate. Thus, four sets of topographic conditions (UPD, 8-ground, UPL and Random) were examined. After the tests, a scanning electron microscope (SEM) was used to reveal the morphology of the transfer film formed on the steel plates. Roughness analysis of the steel plate surfaces was performed using an optical profilometer.

III. RESULTS AND DISCUSSION

It was observed that the coefficient of friction (COF) did not vary significantly for normal loads up to 120N. The variation of average COF with surfaces texture when UHMWPE pins were slid on steel plates of varying roughness under dry condition is shown in Fig. 1. The error bars in the figure indicate the maximum and minimum values of the friction and surface roughness ($R_s$) of a particular surface texture. Each symbol on Fig. 1 is the average COF of five roughness of the same texture. From Fig. 1, it can be noticed that the COF depends considerably on the surface texture. It can be observed that the COF 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. Interestingly, it was observed that the COF values for the same $R_s$ values of two different textured surfaces were significantly different. When the correlation coefficient analysis was performed without considering surface textures, the correlation coefficient between the COF and $R_s$ is 0.82 under dry condition. For a given surface texture, the correlation coefficient between the $R_s$ and COF for UPD, 8-ground, UPL and Random surfaces was found to be 0.86, -0.76, 0.89 and -0.83, respectively.

Fig. 2 shows the backscattered scanning electron micrographs of different textured steel plates that slid against UHMWPE pins under dry condition. From Fig 2, it was noticed that the amount of transfer film 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 also found that the amount of the transfer film formed on the steel plate did not significantly vary with $R_a$. Another interesting point to be noted, though detailed analysis needs to be done, is that the morphology of the UHMWPE transferred is likely to be different for each of the surfaces. It is well known that the morphology of the debris will influence the tribological performance in a joint under actual conditions [6].

![Graph](image)

**Fig. 1:** Variation of coefficient of friction with surface texture and roughness

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 soft materials increases. Such a situation induces a higher level of shear stresses leading to severe shear failure and higher material transfer. This also increases the COF. 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 generated in UPL tests were lower than those in the UPD tests and thus lower COF than 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 COF. For the random surfaces, the COF is lower as the flow is unconstrained. This causes lower stresses, lower COF, and lower amounts of material transfer. Similar frictional response was obtained for metals and alloys during sliding against steel surfaces with different surface textures [5].

**IV. CONCLUSIONS**

The coefficient of friction of UHMWPE predominantly depends on surface texture of harder counter surface. The transfer film formation of UHMWPE depends on coefficient of friction which in-turn depends on the texture of harder counter surface. The effect of surfaces texture on coefficient of friction was attributed to constrained nature of the surfaces at the asperity level during sliding. Thus, the concept of surface textures, in addition to $R_a$, should be considered to understand the frictional analysis in mechanical and biological systems.

**REFERENCES**


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