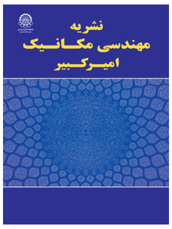

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Transient numerical modeling and experimental investigation of the effect of surface texture on elastohydrodynamic lubrication

A. Torabi[1*] , S. Akbarzadeh[2], B. Azami [2], M. Esfahanian.[2]

[1]Engineering Department, Shahrekord University, Shahrekord, Iran
[2]Mechanical Engineering Department, Isfahan University of Technology, Isfahan, Iran

ABSTRACT: The phenomenon of abrasion and friction in mechanical mechanisms and the ways to reduce them have been highly regarded. One of these methods is surface texturing, which can be accomplished using a laser with high speed and accuracy. These textures usually include holes with different geometric shapes. In this study, a precise numerical model is developed to investigate the frictional behavior of the dimple transient film formation effect. Then the effect of laser-made textures on a ST37 steel disc is studied experimentally in linear contact situation in the mixed lubrication regime. In this study, the friction coefficient is measured after 100m distance for different input important parameters of velocity and vertical load. Numerical results have shown that flow modeling using conventional two-step modeling cause a considerable error and taking about 11 time steps for crossing the dimple is recommended. The friction coefficient decreases with increasing speed and decreasing applied force. Comparison of the results between the textured and smooth discs showed that the friction coefficient decreased by 12 to 23% in the experimental study, while numerical estimates of the possibility of a decrease of between 25 and 40% were also predicted. At high velocities, the numerical model estimates and the results of the experiment are very close.

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1. Introduction

Surface dimples can improve the tribological behavior and help withstand the load by creating hydrostatic pressure in the dimple. These small lubricating holes can extend the operational life of parts. They are also considered as a place to collect worn particles. On the other hand, small dimples are a small lubrication tank.

In this paper, flow modeling is completed by considering the transient contact conditions of a pin over a textured surface. This modification corrects the error in previous modeling and gives a better estimate of lubrication conditions. Then, modeling findings are validated experimentally to evaluate the results and trends of friction coefficient changes with real conditions.

2. Methodology

For modeling, the geometry, load, speed and lubricant characteristics are considered as input data. The governing equation is the well-known Reynolds equation [1]. For non-conformal surfaces, very high lubricant pressures cause the elastic deformation of contact are in order of the film thickness which is called elastohyrodynamic lubrication. When a cylinder passes over a dimple, the geometry of contact area changes with time. The position of the dimple relative to the cylinder can have a significant effect on flow analysis and pressure distribution. This effect can be modeled in Reynolds equations by considering the transient change of film thickness.

For experimental investigation, a pin-on-disk tribological device was used. The discs are made of relatively soft metal such as ST37 steel, which has a hardness of 220 Vickers. The material of the pins used in the tests is 52100 bearing steel with a hardness of 800 Vickers. A Nd: YAG laser was used to create circular holes on the surface of the disk. Hemispherical cavities with a diameter of 400 µm and a depth of about 30 µm were created on the surface. Also, an optimal density of 12% for the texture in the 5-row mode was considered. In this study, ISO VG-68 hydraulic oil with a viscosity of 68 cSt was used as a lubricant. To investigate the effect of surface patterning on the friction behavior of surfaces, tests were performed under three different loads of 50, 100 and 140 N and two different speeds of 0.085 and 0.215 m/s.

3. Results and Discussion

In prior studies, the crossing pin over the dimple was not considered and only the conditions of mating pin and the dimple at center compare with the situation of pin and flat disk contact. In this paper, the transient conditions of textured disk and pin contact are specifically considered. By selecting the appropriate time step, the crossing from the hole is solved as a set of time-varying contact conditions. It is important to note that more time steps can better reflect the effect of the contact surface passing through the cavity, but also increase the calculation cost. Based on the results (Table 1), it was found that 11 time steps can give a better estimate of the transient conditions of crossing the hole.

*Corresponding author's email: torabi@sku.ac.ir

Table 1. Variation of frication coefficient with number of time step

No. time step	Friction coefficient	Variaition (%)	No. time step	Friction coefficient	Variaition (%)
2	0.0408		**9**	0.0552	4.74
3	0.0577	41.38	**10**	0.0552	0.07
4	0.0607	5.27	**11**	0.0542	-1.78
5	0.0490	-19.22	**12**	0.0547	0.88
6	0.0558	13.83	**13**	0.0547	0.06
7	0.0570	2.15	**14**	0.0545	-0.37
8	0.0527	-7.63	**15**	0.0545	-0.1

Table 2. Test conditions and the results of simulated and experimental data for plain and textured disk

Test number	Speed (m/s)	Load (N)	Simulated friction coefficient		Experimental friction coefficient	
			Textured	Plain	Textured	Plain
1	0.085	50	0.022	0.023	0.09497	0.11575
2	0.085	100	0.0687	0.716	0.14343	0.17057
3	0.085	140	0.1442	0.1495	0.18883	0.2147
4	0.215	50	0.043	0.0442	0.09053	0.10803
5	0.215	100	0.1394	0.1457	0.12997	0.15503
6	0.215	140	0.1642	0.1733	0.1523	0.1887

The effect of holes on the load is very noticeable, especially at low loads. In these loads, the coefficient of friction shows a reduction of nearly 40%. While at higher loads this improvement reaches 25%. The cause of this phenomenon is the creation of wide pressure distribution with lower maximums and greater lubricant thickness. Thus, the shear stress across the lubricant layer is reduced and the coefficient of friction due to the shear layer shear reduction is reduced.

At low speeds, about 30% improvement is seen and at higher speeds the effect is more significant and up to 40% improvement is observed. The slope of increasing the coefficient of friction on textured surface is also significantly lower than the non-textured surface, which is also considered a desirable feature. The reason for the improvement of coefficient of friction in this state should be sought in the thickening of the lubricant film and the reduction of shear stress across the lubricant layer.

According to the experimental tests (Table 2), the conditions were also evaluated numerically and the results obtained from the plain mode and if there is texture is presented. As it is clear from the experiments, the contact conditions were not purely governed by hydrodynamic or elastohydrodynamic lubrication. The surface has a roughness and its friction effect has not been seen in the numerical model.

The trend of variation of both the numerical and experimental results on the load is similar to each other. In the numerical results, an increase in the coefficient of friction was observed with increasing load. The increase in velocity increase the friction coefficient, contrary to the experimental results which show a decrease in this coefficient. This difference is clearly due to the assumption of elastohydrodynamic lubrication and the ignoring of modeling the interaction of roughness in numerical solution. Interestingly, at high speeds, the results of numerical calculations approach experimental measurements and the error reach about 8%. This is due to the fact that the lubrication conditions in this cases approach to condition of elastohydrodynamics lubrication.

Comparing the experimental results with each other, it was found that the coefficient of friction for textured disks was reduced by about 14 to 21% compared to plain disks. This quantity is about 4% for numerical estimation.

4. Conclusions

Because the bore of the dimple is large in comparison with the thickness of the lubricating layer, it strongly affects the flow. Flow modeling at the moment when the dimple is in the middle of the contact area and considering it for entire time of crossing pin over the dimple causes an error in estimating the coefficient of friction and to improve this estimation in this paper it was examined and found that modeling with eleven time steps gives better results.

Also, the ability of the model to estimate the pressure distribution and coefficient of friction was demonstrated by examining the effect of the textured surface at different load and velocity conditions. It was found that the coefficient of friction increases with increasing load and speed.

In this study, the effect of dimple in conditions close to elastohydrodynamic and mixed conditions was investigated experimentally, which showed a reduction of about 14 to 21% of the coefficient of friction for textured disks. The numerical and experimental results at high speeds were close to each other, which indicates the establishment of elastohydrodynamic regime and modeling accuracy.

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