Proceedings of Malaysian International Tribology Conference 2015, pp. 157-158, November 2015

Hydrodynamic lubrication of surface textured lubricated contacts with boundary slip using CFD

M. Tauviqirrahman[1,*], Muchammad[2], A.W. Pratomo[1], J. Jamari[1], D.J. Schipper[2]

[1)] Laboratory for Engineering Design and Tribology, Department of Mechanical Engineering, University of Diponegoro, Jl. Prof. Soedarto, SH, Tembalang, Semarang 50275, Indonesia.
[2)] Laboratory for Surface Technology and Tribology, Faculty of Engineering Technology, University of Twente, Drienerloolan 5, Postbox 217, 7500 AE, Enschede, The Netherlands.

[*]Corresponding e-mail: mtauviq99@gmail.com

Keywords: CFD (computational fluid dynamic); slip; texture

ABSTRACT – In this paper, the effect of boundary slip and surface texturing on the lubrication performance is discussed, based on a CFD model. In order to model hydrophobicity, the enhanced user-defined-function (UDF) in the FLUENT package was developed. It is shown that a hydrophobic textured surface is superior to a hydrophilic textured one. The results also show that compared to a well-chosen complex boundary slip flat surface, a textured surface is still less efficient to increase the load support even if the hydrophobic property is used in the textured region.

1. INTRODUCTION

Miniaturization as well as the rapid development of micro-electro-mechanical-systems (MEMS) has attracted great attention. Many MEMS devices include moving (sliding/rolling) surfaces and thus it is necessary to apply a lubricant between the contacting surfaces to reduce friction and wear. The general purpose of lubrication is to minimize friction, wear, and heating of machine components which move relative to each other. In order to improve the lubrication performance, boundary slip and surface texturing have been introduced. As known from previous research, surface texturing as well as surface slippage is an effective means of controlling lubrication performance in lubricated sliding contacts [1-10]. The most promising technique originates from investigations by modifying the contacting surface in a controlled way by laser surface texturing (LST).

The analysis of textured and/or slip surface system generally has been carried out using the Reynolds equation [1-4,7-10]. However, with the increase of complex geometries for which the Reynolds equation is unsuited and the availability of user-friendly, commercial CFD codes based on the Navier-Stokes equations, the application of CFD simulation is quite effective [5,6].

In this paper, a user-defined-function (UDF) to model boundary slip in the FLUENT® package is developed to simulate the effect of a hydrophobic surface in a deterministic way. In the computations conducted, the predicted lubrication performance (pressure and thus load support) induced by boundary slip and surface texturing is simultaneously evaluated and compared with the performance of an optimum operating smooth (without texturing) sliding contact.

2. METHOD

Figure 1 presents a lubricated parallel sliding contact with surface texturing and boundary slip. To analyze the effect of texturing and the slip, the Navier–Stokes equations (Eqs. 1) are solved over the domain using a finite-volume method with the commercial CFD software package FLUENT®. In order to model the slip behavior in FLUENT®, it is necessary to make an additional subroutine to enhance FLUENT's capability and customize its feature for lubrication modeling analysis. This subroutine is called as User-Defined-Function (UDF) [11].

$$\rho(\mathbf{u} \bullet \nabla)\mathbf{u} = -\nabla p + \eta \nabla^2 \mathbf{u} \quad (1a)$$

$$\nabla \bullet \mathbf{u} = 0 \quad (1b)$$

The simulations have been carried out for various cases: (1) no-slip contact, (2) complex slip contact, (3) hydrophilic partially textured contact, (4) hydrophobic partially textured contact. In the present paper, simulation results will be presented in non-dimensional form.

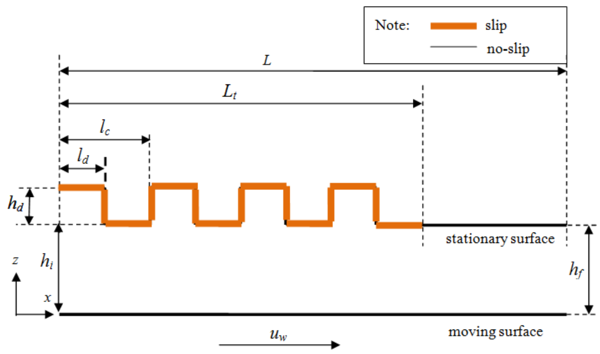

Figure 1 Schematic of a lubricated parallel sliding contact with boundary slip and surface texture. (Note: l_d = dimple length, l_c = texture cell length, h_d = dimple depth, h_i = inlet film thickness, $h_f = h_o$ = land film thickness, L_t = length of textured zone, L = total length of lubricated contact, u_w = moving wall velocity).

3. RESULTS AND DISCUSSION

Recently, in addition to the surface texturing, the use of complex slip has become popular with respect to lubrication, since this type of surface enhancement would give a better tribological performance. In this paper, all parameters including the length of the slip region L_s, length of the texturing zone L_t, and the texture cell aspect ratio λ (where $\lambda = l_d / h_d$) have been initially optimized (see Table 1). As can be seen in Table 1, the maximum improvement in load support, w^+ (where $w^+ = wh_o^2 / \left(u_w \eta L^2\right)$), is obtained for the artificial complex slip surface (about 100% larger). For the hydrophobic partially textured pattern, the computation predicts a 95% improvement. The partially hydrophilic textured surface (without slippage) does not increase load support, $w^+ = 0.155$ which means that a decrease in w+ is noticed (3% lower). So, with respect to the load support, while the hydrophobic textured surface with boundary slip is superior to the textured surface alone, it is not as effective as the smooth configuration with a complex slip.

The comparison of the predicted pressure is presented in Figure 2. It is shown that the highest pressure is found for the smooth slip surface situation in which the pressure value is approximately three times as large as the maximum pressure obtained from those without slip. It is interesting to note that in a real application, for example in lubricated-MEMS containing moving surfaces, the fact that load support can be produced by an artificial complex slip surface on a perfectly smooth surface seems to be a very promising way for designing highly loaded lubricated mechanisms.

Table 1 Optimized lubricated contact characteristics

Contact type	Type	h_i/h_o	L_s/L	L_t/L	λ	w^+
Classical	1	2.2	-	-	-	0.16
Complex slippage	2	1	0.65	-	-	0.33
Hydrophilic textured	3	1	-	0.55	5	0.155
Hydrophobic textured	4	1	0.55	0.55	5	0.32

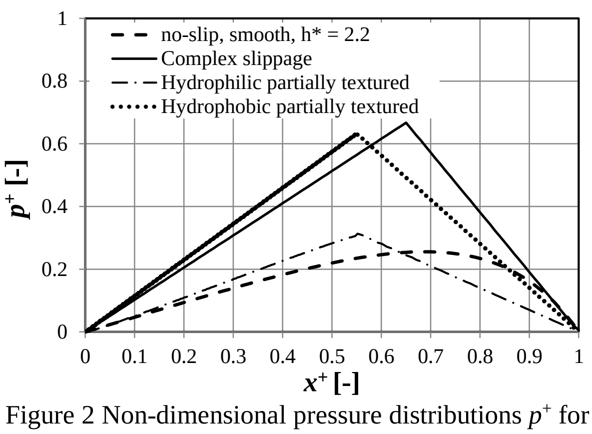

Figure 2 Non-dimensional pressure distributions p^+ for various cases. (Note: $p^+ = ph_o^2 / \left(u_w \eta L\right)$ and $x^+ = x/L$).

4. CONCLUSIONS

The aim of the investigation was to examine the effect of the hydrophobic surfaces combined with surface texturing by using CFD software. The present results explain the connection between surface texturing and hydrophobicity (boundary slip) in a deterministic way. Indeed, an effective hydrophobic textured surface, as indicated in this paper, can be utilized as a guideline for the fabrication of modified sliding surfaces, for instance, in lubricated-MEMS.

5. REFERENCES

[1] R.F. Salant, and A.E. Fortier, "Numerical analysis of a slider bearing with a heterogeneous slip/no-slip surface," *Tribology Transactions*, vol. 47, pp. 328-334, 2004.

[2] J.H., Choo, H.A. Spikes, M. Ratoi, R.P. Glovnea, and A.K. Forrest, "Friction reduction in low-load hydrodynamic lubrication with a hydrophobic surface," *Tribology International*, vol. 40, pp.154-159, 2007.

[3] R. Rahmani, A. Shirvani, and H. Shirvani, "Optimization of partially textured parallel thrust bearings with square-shaped micro dimple," *Tribology Transactions*, vol. 50, pp. 401-406, 2007.

[4] M.B. Dobrica, and M. Fillon, "About the validity of Reynolds equation and inertia effects in textured sliders of infinite width," *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, vol. 223. pp. 69-78, 2009.

[5] J. Han, L. Fang, J. Sun, and S. Ge, "Hydrodynamic lubrication of microdimple textured surface using three-dimensional CFD," *Tribology Transactions*, vol. 53, pp. 860-870, 2010.

[6] X. Shi, and T. Ni, "Effects of groove textures on fully lubricated sliding with cavitation," *Tribology International*, vol 44, pp. 2022-2028, 2011.

[7] I.S.Y. Ku, T. Reddyhoff, R. Wayte, J.H. Choo, A.S. Holmes, and H.A. Spikes, "Lubrication of microelectromechanical devices using liquids of different viscosities," ASME *Journal of Tribology*, vol. 134, pp. 012002-1-7, 2013.

[8] F. Aurelian, M. Patrick, and Mohamed H, "Wall slip effects in (elasto) hydrodynamic journal bearing," *Tribology International*, vol. 44, pp. 868-877, 2011.

[9] M. Tauviqirrahman, Muchammad, Jamari, and D.J. Schipper, "Numerical study of the load carrying capacity of lubricated parallel sliding textured surfaces including wall slip," *Tribology Transactions*, vol. 57, no. 1, pp. 134–145, 2014.

[10] T.V.V.L.N. Rao, A.M.A. Rani, T. Nagarajan, and F.M. Hashim, "Analysis of slider and journal bearing using partially textured slip surface," *Tribology International*, vol. 56, pp.121-128, 2012.

[11] ANSYS FLUENT 12 UDF Manual 2009.