Numerical investigation of the combined effects of slip and texture on tribological performance of bearing

by Mohammad Tauviqirrahman

Tribology - Materials, Surfaces & Interfaces

ISSN: 1751-5831 (Print) 1751-584X (Online) Journal homepage: http://www.tandfonline.com/loi/ytrb20

Numerical investigation of the combined effects of slip and texture on tribological performance of bearing

S. Susilowati, M. Tauviqirrahman, J. Jamari & A. P. Bayuseno

To cite this article: S. Susilowati, M. Tauviqirrahman, J. Jamari & A. P. Bayuseno (2016) Numerical investigation of the combined effects of slip and texture on tribological performance of bearing, Tribology - Materials, Surfaces & Interfaces, 10:2, 85-88, DOI: 10.1080/17515831.2016.1159781

To link to this article: http://dx.doi.org/10.1080/17515831.2016.1159781

Published online: 02 Jun 2016.

Numerical investigation of the combined effects of slip and texture on tribological performance of bearing

S. Susilowati[1,2], M. Tauviqirrahman[2], J. Jamari[2] and A. P. Bayuseno[2]

Slider bearings are used in many applications. An increase in the load support may allow for saving of energy. In this work, in order to enhance the load support and decrease the friction force, a combined textured surface bearing using boundary slip is discussed. A modified Reynolds equation with slip is adopted. With the main goal of evaluating the effects of slip and texture, a parametric analysis is performed. For the given operating conditions, texturing features as well as slip pattern are analysed in detail. The numerical analysis is undertaken under the condition of different gap ratio values and the slip-textured area. The results show that combined techniques of slip and texture have a significant effect on the improvement of the tribological performance of bearing, that is, a high load support but low friction force. The gap ratio of the bearing is shown to have a significant effect on the lubrication behaviour. It is found that even with a smallest gap ratio (parallel gap), a high load support can be produced. However, it is also shown that the gap ratio appears to contribute to the generated friction force and the volume flow rate more than the boundary slip. Further analysis indicates that the optimum slip-text zones for certain gap ratio are highlighted. These findings may provide references for designing hydrodynamic-textured slider bearing considering boundary slip.

Keywords: Boundary slip, Gap ratio, Texture

The research was originally accepted for and presented at MITC 2015.

Introduction

As commonly known, surface texturing has been considered as a technique to improve the tribological performance of the bearing. For example, Rahmani *et al.*,[1] explored the effect of variations of the three main geometrical parameters of square-shaped dimples on the lubrication performances, i.e. load support, the friction force and the friction coefficient of partial surface-textured parallel slider bearings. It was shown that for partial-textured surfaces, increasing the number of dimples would not help in improving either the load support or the friction coefficient. Han *et al.*,[2] presented a three-dimensional hydrodynamic lubrication model of the incompressible Newtonian fluid on the textured surface with a single spherical cap microdimple based on the full Navier-Stokes equation. The result showed that the load support of the lubrication film is monotonously improved with increasing microdimple width and Reynolds number, and a reverse tendency is found for friction force and friction coefficient. Gherca *et al.*,[3] performed geometrical investigation of surface textures. It was revealed that the effect of the groove shape was strongly related to those of the other geometrical parameters such as the inlet length in the case of a single-grooved bearing or the cell number in the case of textures. Scaraggi *et al.*,[4] investigated the frictional behaviour of laser surface texturing (LST) surfaces under lubricated conditions. It was found that when the texture consists of a square lattice of microholes, the friction values are strongly reduced over the entire range of lubrication regimes with a maximum reduction of about 50% in hydrodynamic conditions. Charitopoulos *et al.*,[5] presented a computational investigation of thermohydrodynamic performance and mechanical deformations of a fixed-geometry thrust bearing with artificial surface texturing. The bearing stator was partially textured with square dimples. A CFD-based THD analysis has been performed, along with a one-way fluid–structure interaction (FSI) coupling. They concluded that due to heating oil, the load carrying capacity decreases with the rotational speed. Generally speaking, from the previous studies, using textured surfaces for contact performance has been proven to enhance the load support and/or reduce the friction force.

Recently, in addition to the surface texturing, the introduction of boundary slip to contacted surfaces is considered as a method to improve the lubrication performances. Direct experimental[6,7] and numerical evidences[8–13] have also been presented to show that the boundary slip can alter the flow pattern of the lubrication behaviour of the bearing. In this way, the boundary slip, as well as surface texturing, can be engineered to generate a positive effect with respect to the lubrication performance.

[1]Faculty of Industrial Technology, Laboratory for Research and Unit Operation of Chemical Engineering, Chemical Engineering Department, Universitas Pembangunan Nasional "Veteran", Surabaya 60294, Indonesia
[2]Laboratory for Engineering Design and Tribology, Department of Mechanical Engineering, University of Diponegoro, Semarang 50275, Indonesia

*Corresponding author: email zuzisukasno@gmail.com

Received 7 September 2015; accepted 24 February 2016
DOI 10.1080/17515831.2016.1159781

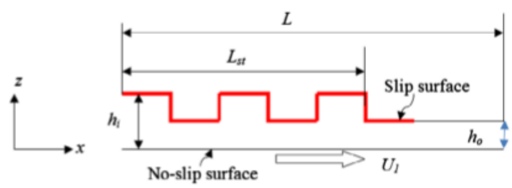
Based on the literature survey, very few researchers appear to have considered the interplay of the surface texture and the boundary slip on tribological performance. Tauviqirrahman *et al.*,[9,10] explored the possibility of slip and texture in order to enhance the lubrication performance characteristics (hydrodynamic pressure, load carrying capacity and friction force). Their results show that the combined texture/slip configuration increases load carrying capacity and decreases friction. Also, the optimal slip area and texture geometry as well as the slip-texture feature are highlighted. Rao *et al.*,[11] investigated the partially textured slip slider bearing using modified classical Reynolds equation on the basis of Navier slip model. It was shown that partially textured slip has a potential to produce load carrying capacity even for parallel sliding contact. Later, Aurelian *et al.*,[12] explored the effect of slip on load carrying capacity and power loss in hydrodynamically lubricated bearings. A simple slip-textured combination was investigated using modified slip length model. The main conclusion was that when choosing a texture/slip-zone pattern, it should be done carefully because an inappropriate choice can lead to a drastic deterioration of the lubrication performance. In a recent publication, Wang and Lu[13] have shown that boundary slip decreases oil-film pressure, carrying capacity, friction drag and temperature rise but increases end leakage and cavitation region.

In order to extend the complement findings[9,10], this paper is intended to explore the wedge effect due to the presence of the gap ratio for slider bearing by combining the slip and the texturing in full hydrodynamic lubrication by numerical analysis. The modified Reynolds equation presented here is developed from the work of Tauviqirrahman *et al.*[9,10] by including the wedge term. Based on the proposed model, the load support, the friction force and the flow rate behaviour are studied under various gap ratio values of the bearing and particular slip-texture configuration.

Numerical method

The derivation of the classical Reynolds equation with a Newtonian lubricant is based on the assumption of no slip between the lubricant and the surfaces. The model of lubrication presented here is based on the fact that slip at the interface between the lubricant and surface will exist. The proposed boundary slip model leads to a modified Reynolds equation. In the present work, the proposed model as well as the steps of derivation of such mathematical model is similar to the lubrication model published by Tauviqirrahman *et al.*[9] However, the modified Reynolds equation presented here is extended to include the wedge effect. Such a lubrication system can be described with the modified Reynolds equation as follows:

$$
\begin{aligned}
&\frac{\partial}{\partial x}\left(h^3\frac{h^2+4h\mu(\alpha_a+\alpha_b)+12\mu^2\alpha_a\alpha_b}{h(h+\mu(\alpha_a+\alpha_b))}\frac{\partial p}{\partial x}\right)\\
&=6\mu U\frac{\partial}{\partial x}\left(\frac{h^2+2h\alpha_a\mu}{h+\mu(\alpha_a+\alpha_b)}\right)-6\mu\tau_{ca}\frac{\partial}{\partial x}\left(\frac{\alpha_a h(h+2\alpha_b\mu)}{h+\mu(\alpha_a+\alpha_b)}\right)\\
&+6\mu\tau_{cb}\frac{\partial}{\partial x}\left(\frac{\alpha_b h(h+2\alpha_a\mu)}{h+\mu(\alpha_a+\alpha_b)}\right)-12\mu U_1\frac{\alpha_a\mu}{h+\mu(\alpha_a+\alpha_b)}\frac{\partial h}{\partial x}\\
&+6h\frac{\partial p}{\partial x}\frac{\partial h}{\partial x}\frac{h\alpha_a\mu+2\alpha_a\alpha_b\mu^2}{h+\mu(\alpha_a+\alpha_b)}+12\mu\tau_{ca}\left(\frac{\alpha_a(h+\alpha_b\mu)}{h+\mu(\alpha_a+\alpha_b)}\frac{\partial h}{\partial x}\right)\\
&-12\mu\tau_{cb}\left(\frac{\alpha_a\alpha_b\mu}{h+\mu(\alpha_a+\alpha_b)}\frac{\partial h}{\partial x}\right) \qquad (1)
\end{aligned}
$$



1 Schematic of a lubricated parallel sliding contact with boundary slip and surface texture
(Note: h_i = inlet film thickness, h_o = outlet film thickness, L_{st} = length of slip-textured zone, L = total length of lubricated contact, U_1 = moving wall velocity)

It is worth noting that the slip length model is used to address the modelling of the boundary slip for the hydrodynamic analysis after the shear stress exceeds the limiting shear stress. It should be noted that Equation (1) has considered the wedge effect (i.e. the fourth, sixth, and seventh terms in right side of Equation (1)). According to the classical Reynolds theory, a gap ratio is one of the most important conditions to generate a hydrodynamic pressure. It should be noted that the gap ratio leads to the wedge effect.[14] From the physical point of view, in terms of the wedge term, for positive load support, the thickness of the lubricant film must decrease in the sliding direction. In this work, it will be shown that introducing the boundary slip could minimise the wedge effect.

In the present work, the physical configuration of slip-textured bearing is simplified to focus on the variation of the slip-texture zone configuration varying the gap ratio as shown in Fig. 1. The slip and texturing techniques are applied on the stationary surface. In this work, gap ratio of the bearing is defined as ratio of the inlet film thickness (h_i) over the outlet film thickness (h_o) as depicted in Fig. 1.

The physical meanings of the symbols in Equation (1) are as follows: h the film thickness (gap) at location, p the lubrication film pressure, α the slip coefficient, τ_c the critical shear stress (subscripts a and b denote the stationary and moving surface, respectively) and μ the lubricant viscosity. The product of the slip coefficient with the viscosity, $\alpha\mu$, is named 'hydrophobicity coefficient, b'. In the present work, the critical shear stress is set to zero to achieve the highest hydrodynamic pressure.[9]

The modified Reynolds equation (1) is discretised over the flow using the finite volume method, and is solved using tridiagonal matrix algorithm (TDMA).[15] By employing the discretisation scheme, the computed domain is divided into a number of control volumes using a grid with uniform mesh size. The grid independency is validated by various numbers of mesh sizes. An assumption is made that the boundary pressures are null at both sides of the contact. However, the Reynolds cavitation model is adopted.

The simulation results will be presented in dimensionless form, i.e.

$$W = wh_i^2/(U_1\mu L^2) \qquad (2)$$

$$F = fh_i/\mu U_1 L \qquad (3)$$

$$Q = q\ /\ hU_1 \qquad (4)$$

W is denoted for dimensionless load support in which w is the load per unit length, and μ = the lubricant viscosity. The load support is determined by integrating the calculated hydrodynamic pressure. F is denoted for dimensionless friction force (where f is the unit width friction force). In this case, the shear stress at the stationary surface is integrated to determine the friction force. Finally, Q is denoted for dimensionless volume flow where q is the unit width volume flow.

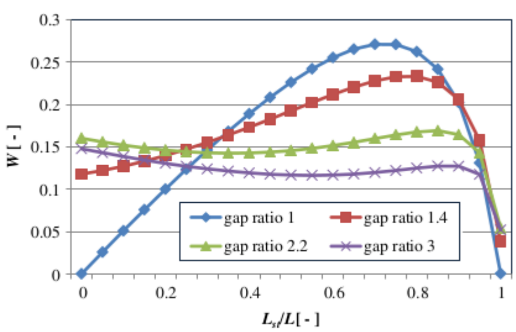
Results and discussion

As is well known, the surface texturing, as well as the boundary slip, plays a vital role in the lubrication performance. In a real system, the surface texturing can be made by modifying the contacting surfaces in a controlled way by laser surface texturing. Friction force reduction was observed with the introduction of the different patterns in the form of microtextures at the surface. The boundary slip can also be a promising way for increasing the load carrying capacity and reducing the friction force. The slip surface can be engineered by modifying the geometrical micro- or nanostructure of the surface and controlling in this way the surface energy. Micro-structured pattern can be made using lithographic techniques, plasma etching or metal-assisted etching. This method is then followed by hydrophobic treatment which can be accomplished by techniques such as film or molecule deposition, solution coating or self-assembly of hydrophobic layers.[16]

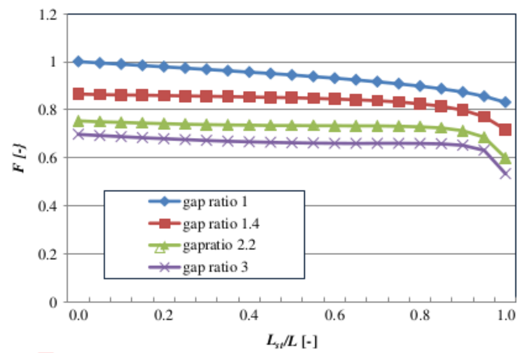
The primary parameters of the lubricated sliding contact are given as follows: sliding velocity U is 1 m/s, the total length of lubricated contact L is 20×10^{-3} m and outlet film thickness h_o is 1×10^{-6} m. In the following simulations, the slip coefficient α is set to 0.1 m²/s/kg (the corresponding slip length is 1×10^{-4} m) based on the results published in literature.[6] The slip-texturing zone varies from 0 (i.e. smooth surface) to L (i.e. full texturing). In this work, the texture depth d is assumed to equal to h_o. As a consequence, depending on the gap ratio, the h_i can be altered by raising the top surface.

Figure 2 shows the influence of the length of slip-textured zone, L_{st} on the dimensionless fluid load support W at various gap ratios of the bearing. It can be observed that when $L_{st} = 0.65\,L$ for gap ratio of 1 (i.e. parallel sliding bearing), the load support achieves the maximum value. It is interesting to note, that this result is quite similar to the modified smooth bearing with boundary slip.[9,17] As shown in this Figure, the maximum pressure distribution for a parallel surface using the optimised slip-textured zone ($L_{st}/L = 0.65$) is approximately three times as large as the maximum pressure obtained from a no-slip wedge when the gap ratio is 2.2. The most possible explanation is that by introducing the boundary slip at the leading edge of the contact, the volume flow induced by solid surface velocities can be larger than that at the outlet in order to keep a constant volume flow. In addition, based on Fig. 2, it can be stated that when $L_{st} = L$ for gap ratio of 1, the load support W becomes zero, while for other gap ratio values, the hydrodynamic pressure presents. This indicates that the wedge effect plays a dominant role to create the pressure rather than the full slip effect.

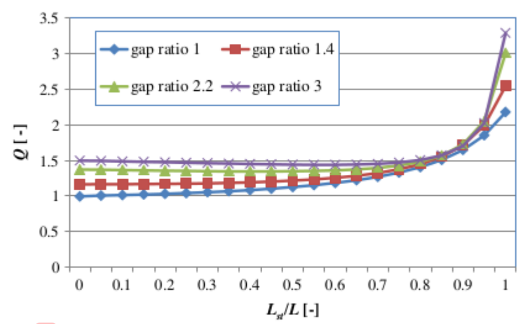
Figure 3 shows the influence of the length of slip-textured zone, L_{st} on the dimensionless friction force F at various gap ratios of the bearing. Based on this figure, the minimum friction force is achieved for all ranges of the length of slip-textured zone when the gap ratio of 3 is applied at the



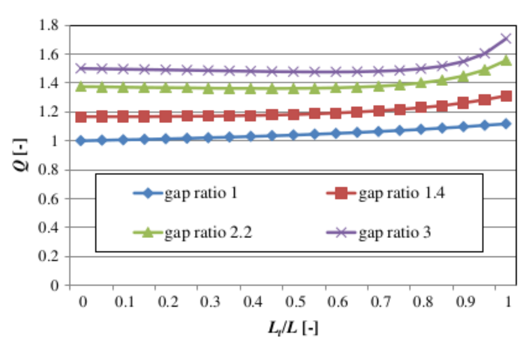
2 Effect of the length of slip-textured zone, L_{ss} on the dimensionless fluid load support W at various gap ratios of the bearing



3 Effect of the length of slip-textured zone, L_{st} on the dimensionless friction force F at various gap ratios of the bearing



4 Effect of the length of slip-textured zone, L_{st} on the dimensionless flow rate Q at various gap ratios of the bearing



5 Effect of the length of textured zone, L_t on the dimensionless flow rate Q at various gap ratios of the bearing

bearing. This is as expected because the wedge effect, due to the presence of the gap ratio of the bearing, leads to the decrease in the friction force. When slip is applied on the texture, the wall shear stress becomes smaller and thus the reduced friction force. The combined effects of the gap ratio and the presence of the boundary slip reduce the friction force.

Figure 4 shows the effect of the length of slip-textured zone, L_{st} on the dimensionless flow rate Q at various gap ratios of the bearing. It can be seen that for a specific gap ratio, the flow rate tends to increase, and after the length of the full slip texturing achieves the value of 0.8, the flow rate increases significantly. This is different with the case when the slip is absent (Fig. 5). The flow rate increases with a very low rate. When full slip texturing is applied, the flow rate value is highest. In addition, based on Figure 5, it can be observed that the increase in length of textured zone will increase the flow rate. This trend prevails for all the values of slope incline ratio considered here.

Conclusions

A numerical model based on finite volume method was developed to investigate the slip-texture configuration influence on the bearing surface of a hydrodynamic slider bearing subjected to the gap ratio. In this paper, the wedge effect of slip-textured bearing has been taken into account by analysing the presence of the gap ratio. Different arrangements of the slip-textured area have been considered. The studies in this paper are summarised as follows:

(i) For maximum load support, the length of slip-textured zone is set to 0.65 while the bearing configuration used is parallel.

(ii) Full texturing with slip leads to a decrease in the friction force significantly for all gap ratio values. However, the minimum friction force is achieved when the gap ratio of the bearing is high.

(iii) Boundary slip combined with the texture appears effective to improve the flow rate compared to the conventional textured surface.

(iv) The slip-textured zone optimum design depends strongly on the gap ratio.

ORCID

M. Tauviqirrahman http://orcid.org/0000-0003-2694-4184

References

1. R. Rahmani, A. Shirvani and H. Shirvani: 'Optimization of partially textured parallel thrust bearings with square-shaped micro-dimples', Tribol. Trans., 2007, **50**, 401–406.
2. J. Han, L. Fang, J. Sun and S. Ge: 'Hydrodynamic lubrication of microdimple textured surface using three-dimensional CFD,' Tribol. Trans., 2010, **53**, 860–870.
3. A. R. Gherca, P. Maspeyrot, M. Hajjam and A. Fatu: 'Influence of texture geometry on the hydrodynamic performances of parallel bearings', Tribol. Trans., 2013, **56**, 321–332.
4. M. Scaraggi, F. P. Mezzapesa, G. Carbone, A. Ancona and L. Tricarico: 'Friction properties of lubricated laser-microtextured-surfaces: an experimental study from boundary- to hydrodynamic-lubrication,' Tribol. Lett., 2013, **49**, 117–125.
5. A. Charitopoulos, D. Fouflias, C. I. Papadopoulos, L. Kaiktsis and M. Fillon: 'Thermohydrodynamic analysis of a textured sector-pad thrust bearing: effects on mechanical deformations,' Mech. Ind., 2014, **15**, 403–411.
6. J. H. Choo, R. P. Glovnea, A. K. Forrest and H. A. Spikes: 'A low friction bearing based on liquid slip at the wall,' J. Tribol., 2007, **129**, 611–620.
7. 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,' *Tribol. Int.*, 2007, **40**, 154–159.
8. R. F. Salant and A. E. Fortier: 'Numerical analysis of a slider bearing with a heterogeneous slip/no-slip surface,' Tribol. Trans., 2004, **47**, 328–334.
9. M. Tauviqirrahman, M. Muchammad, J. Jamari and D. J. Schipper: 'Numerical study of the load carrying capacity of lubricated parallel sliding textured surfaces including wall slip,' Tribol. Trans., 2014, **57**, (1), 134–145.
10. M. Tauviqirrahman, R. Ismail, J. Jamari and D. J. Schipper: 'Combined effects of texturing and slippage in lubricated parallel sliding contact', Tribol. Int., 2013, **66**, 274–281.
11. 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,' *Tribol. Int.*, 2012, **56**, 121–128.
12. F. Aurelian, M. Patrick and H. Mohamed: 'Wall slip effects in (elasto) hydrodynamic journal bearings,' Tribol. Int., 2011, **44**, 868–877.
13. L.-L. Wang and C.-H. Lu: 'Numerical analysis of spiral oil wedge sleeve bearing including cavitation and wall slip effects,' Lubr. Sci., 2015, **27**, (3), 193–207.
14. B. J. Hamrock, S. R. Schmid and B. O. Jacobson: 'Fundamental of fluid film lubrication- second edition,' 2004, New York, NY, Marcel Dekker, Marcel Dekker,
15. S. V. Patankar: 'Numerical heat transfer and fluid flow,' 1980, Levittown, Taylor & Francis.
16. Y. Xiu: 'Fabrication of surface micro-and nanostructures for superhydrophobic surfaces in electric and electronic applications,' PhD thesis, Georgia Institute of Technology, Atlanta, GA, 2008.
17. C. W. Wu, G. J. Ma and P. Zhou: 'Low friction and high load support capacity of slider bearing with a mixed slip surface,' J. Tribol., 2006, **128**, 904–907.

Numerical investigation of the combined effects of slip and texture on tribological performance of bearing

ORIGINALITY REPORT

21%	21%	23%	7%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	ris.utwente.nl Internet Source	10%
2	Susilowati, M. Tauviqirrahman, J. Jamari, A. P. Bayuseno. "The beneficial effect of slip on the hydrodynamic lubrication in the lubricated sliding contact", AIP Publishing, 2017 Publication	4%
3	www.ripublication.com Internet Source	4%
4	M. Tauviqirrahman, R. Ismail, Jamari, D.J. Schipper. "Optimization of the complex slip surface and its effect on the hydrodynamic performance of two-dimensional lubricated contacts", Computers & Fluids, 2013 Publication	3%

Exclude quotes	Off	Exclude matches	< 100 words
Exclude bibliography	Off		

Numerical investigation of the combined effects of slip and texture on tribological performance of bearing

GRADEMARK REPORT

FINAL GRADE

/0

GENERAL COMMENTS

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5