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Numerical Study of Shear Stress Around an Ideal Roughness

In EHD lubrication conditions the viscosity of the lubricants increases, occuring at high shear rates of plastic behavior. Previous researches showed that the shear stress in the film thickness of the lubricant may vary, affecting the lubrication. This paper presents a numerical study on the effect of the presence of an ideal roughness on the flow behavior and the shearing of the lubricant film.

Keywords*: plastic shear, pressure distribution, roughness*

1. Introduction

The plane pad lubrication problem, from the point of view of plastic shear has been previously studied in researches carried out by Huang and Wen [1], Diaconescu [2], Balan [3]. These researches shows that the presence of the plastic shear has a significant effect on the functioning of the contact.

This paper focuses on the specific case of lubrication of a simple triangular ideal roughness, shaped as in Figure 1, from the point of view of the shear stress occurring in the film of the lubricant. The shape of the roughness was modeled with a similar symmetrical form obtained by joining two geometrical known pads.

Previous researches, [4], proved that, by mathematical and physical modelling of the roughness according to a proposed model, can reveal its implications in scuffing occurrence by film consistency loss. By comparing the shear stress at the limits of the plane and of the pad, with shear limit stress, using a Mathcad software there were highlighted the cases with plastic shear presence, mathematically synthesized in Table 1.

The evolution of the pressure distribution will have a similar form to the distribution of pressure for a viscous Newtonian case, but much more reduced, according to the graphs drawn by Diaconescu [2]. It was also assumed that the abscissa corresponding to the maximum pressure, x_{m1},(first pad), and the minimum pressure, x_{m2}, (corresponding to the second pad), are in the areas where the viscous fluid acts. This forms three zones of different behavior of the lubricant (viscous, plastic-viscous and viscous), which should have continuity between them, so there were deduced calculation relations for each area.

Pressure were obtained from the differential equation for the uni-dimensional flow integrated as *x*, considering the speed of the plane, U, and the roughness speed is 0, customized for each pad.

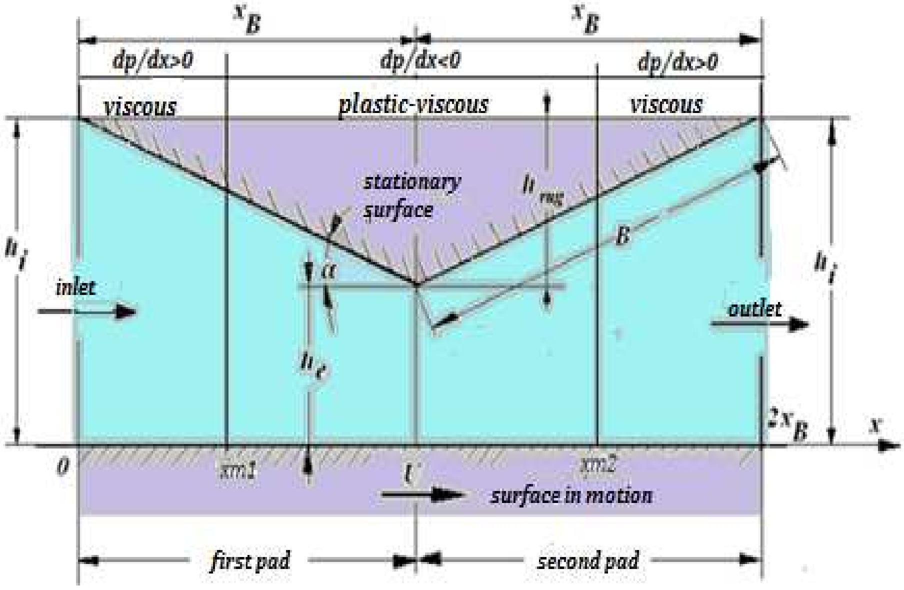

Figure 1. Roughness geometry proposed model, where the shear behavior areas are highlighted.

For the proposed analysis, in this particular case were considered, the following parameters as input to a program written in Mathcad: length $x_b = 0.0025\times10^{-3}$ m, height minimum lubricant film, $h_e = 0.01\times10^{-3}$ m, roughness height; $h_{rug} = 0.0075\times10^{-3}$ m, (ratio of the maximum/minimum lubricant film thickness is $a = \frac{h_i}{h_e} = 1{,}75$). It is also considered that a lubricant is interposed between the roughness and the plan, with the following parameters: plan dynamic viscosity, η = 0.3 [Pa.s], voltage limit atmospheric shear, $\tau_{l0} = 0{,}5\times10^6$ [Pa], the coefficient of stress variation pressure shear limit, β=0.04.

Table 1. Relations that characterize the behavior of the lubricant proposed shear model.

<table>
<tr><th></th><th>Lubricant behavior</th><th>Shear stress expressions</th></tr>
<tr><td>Plastic shearing absent</td><td>$\left|\tau_{\max}\right| \prec \tau_{\lim} = \tau_{l0} + \beta \cdot p$</td><td>$\tau_{VN} = \frac{dp}{dx}\left(z - \frac{h}{2}\right) - \frac{\eta \cdot U}{h}$</td></tr>
<tr><td rowspan="4">Plastic shearing present</td><td>$\left|\tau_{\max}\right| \succ \tau_{\lim} = \tau_{l0} + \beta \cdot p$</td><td></td></tr>
<tr><td>$\frac{dp}{dx} \succ 0$
- viscous-plastic lubricant behavior
- plastic shear on the plane</td><td>$\tau_{GP\succ 0} = \frac{dp}{dx} z - \left(\tau_{l0} + \beta p\right)$</td></tr>
<tr><td>$\frac{dp}{dx} \prec 0$
- plastic - viscous lubricant behavior
- plastic shear on the pad</td><td>$\tau_{GP\prec 0} = \frac{dp}{dx}\left(z - h\right) - \left(\tau_{l0} + \beta \cdot p\right)$</td></tr>
<tr><td>plastic shear on the both surface surfaces
- The top surface
- The bottom</td><td>$\tau_{GP\succ 0} = \frac{dp}{dx}\left(z - h\right) - \left(\tau_{l0} + \beta \cdot p\right)$
$\tau_{GP\prec 0} = \frac{dp}{dx} \cdot z - \left(\tau_{l0} + \beta \cdot p\right)$</td></tr>
<tr><td colspan="3">VP- viscous-plastic, VN- viscous-newtonian, GP - pressure gradient, P- plastic.
$\tau_{\max}, \tau_{\lim}, \tau_{l0}$ - maxim shear stress, limiting shear stress, limiting shear stress at initial pressure
h_{m1}, h_{m2} ,– film thickness where the pressure gradients are zero
u_1, u_2 -rughness and plane speeds;</td></tr>
</table>

From the diagram of the shear stress distribution, obtained in the Mathcad program for this particular case, discontinuities were observed for the tangential shear stress between the four specific behavior areas of the lubricant, in the connection points . The occurrence of plastic shear is evident on the maximum tangential stress evolution graph (Figure 2) where can be seen the areas where plastic shear occurs (between x_1 si x_2) and the maximum and minimum peaks of pressure, x_{m1} respectively x_{m2}, that are moving towards the roughness' peak limits.

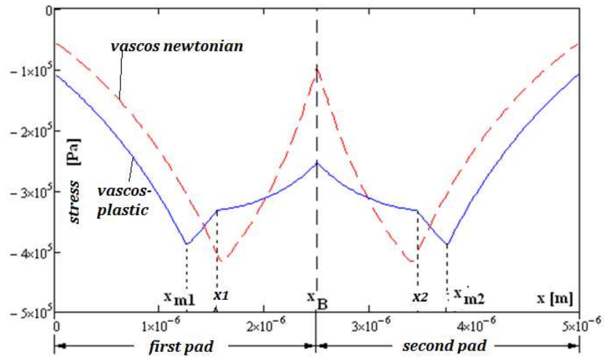

Figure 2. Maximum tangential shear stress along the lubricant film, in the case of occurrence of plastic shear

2. FEM simulation

Taking into account that the lubricants in EHD regime reach very high viscosities, we can model the lubricant layer between an infinitely long ideal roughness and a perfect plane surface through a model with the same lubricant film geometry and a behavior of a solid with a plastic material flow limit.

An Autodesk Multiphysics model was created for the two-dimensional interstitial area between a triangular roughness and a flat surface with a solid elastic-plastic behavior. Roughness peak, h_e, is located at a known distance from the plane surface. The roughness is modeled by two inclined pads with the same length, disposed symmetrically from the median plane. It is considered that roughness is moving on the plane direction. All nodes on the roughness contour can make a displacement on the Y direction, according to the reference system of Figure 3. A 0.03 micrometer displacement was imposed. The nodes from the plane surface will be fixed.

The model is discretized into 400 quadrilateral elements. Pattern length is 16 micrometers, the height at the ends is of one micrometer and the distance from the tip of the roughness to the flat surface is of 0.1 micrometers. The model has an associated material behavior as linear-elastic up to 10,034 MPa, defined by a Young's modulus of 0.1Mpa, then the material start to have a plastic behaviour. The analysis of the model is a 30 steps static one.

3. Results

In Figure 3 is represented the von Mises stress distribution for elastic-plastic behavior for the maximum load (10,034 MPa).

The maximum of the von Mises stress is reached in the median region of the model. This maximum location can be explained by the fact that the model has in this region a minimum height value. Model dimension in the median region of the model is minimal and therefore tensions will be maximal.

Figure 4 present the YZ stress for the maximum load. As in the case of von Mises stress, this stress is also maximum in the median region of the model. Analyzing the values from Figure 4 and Figure 5 it is noticed that the largest part of the value of the von Mises stress is due to the YZ stress. Plastic deformation is mainly due to the YZ stress.

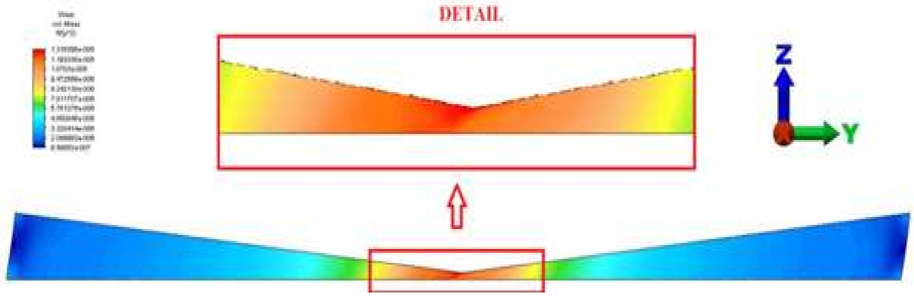

Figure 3. Von Mises stress

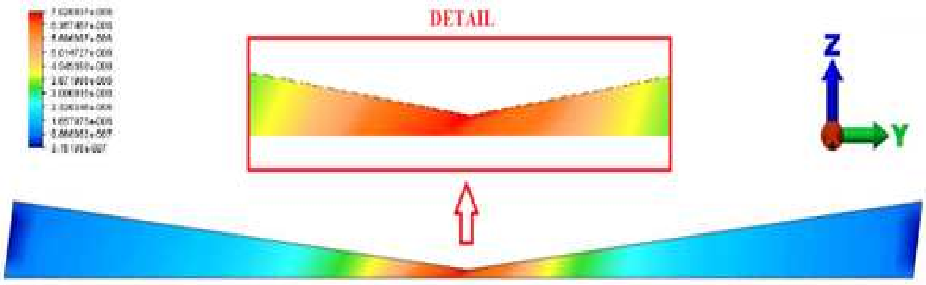

Figure 4. YZ Stress.

4. Conclusion

Mathcad numerical modeling revealed that an increase in the relative velocity leads to the appearance of a plastic shear zone in the vincinity of the peak of the roughness and subsequently extends this initial area at higher speeds.

The finite element model leads to a similar conclusion with the Mathcad results. A stress concentration occurs in the vicinity of the roughness peak and it is expected an enlargement of this zone with increasing the plastic deformation due to relative movement roughness/plane.

The peak of the roughness acts like a stress concentrator.

The stresses distribution into lubricant is dependent on interstitium geometry.

The stress and strains are maximum in the median region of the model where the cross sectional dimension is minimal.

Material plastic stress limit is reached easily in the region of minimum section of the interstitium. These numerical results are in agreement with experimental results (5) which highlight the dependence of scuffing initiation phenomenon with the contact relative speed.

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