39th Solid Mechanics Conference
Zakopane, Poland, September 1–5, 2014

P053

SOFT ELASTOHYDRODYNAMIC LUBRICATION PROBLEMS IN THE FINITE DEFORMATION REGIME: EXPERIMENTAL TESTING AND MODELLING

P. Sadowski, S. Kucharski, J. Lengiewicz, S. Stupkiewicz

Institute of Fundamental Technological Research, Warsaw, Poland

1. Introduction

An increased interest in soft elastohydrodynamic lubrication (soft-EHL) problems is recently observed which is due to important applications in technology (elastomeric seals, tyres, etc.), but also because this lubrication regime occurs in many biotribological systems (e.g., synovial joints, human skin contact, etc.). In hydrodynamic lubrication, contact interaction occurs through a thin film of lubricant in which hydrodynamic pressure builds up when the lubricant is dynamically entrapped between the contacting surfaces. In the elastohydrodynamic lubrication regime, the hydrodynamic pressure is sufficiently high to significantly deform the contacting bodies, which introduces a strong coupling between the fluid flow and the elastic deflections of the contacting members. Finally, the characteristic feature of soft-EHL contacts is that the pressure is relatively low, but the elastohydrodynamic coupling is crucially important because one or both contacting bodies are soft.

When the contacting bodies are soft, relatively low contact pressures may lead to finite deformations of the contacting bodies. The corresponding effects have so far attracted little attention. In this work, the related effects are investigated experimentally and theoretically.

2. Experimental setup

A ball-on-disk setup, see Fig. 1, has been used to experimentally test friction in lubricated contact. The setup has been designed such that a rubber ball can be tested under the normal force that is high enough to result in finite deformations of the ball. The rotation speed, the normal force and the lubricant properties are controlled and the friction force is measured using a load cell.

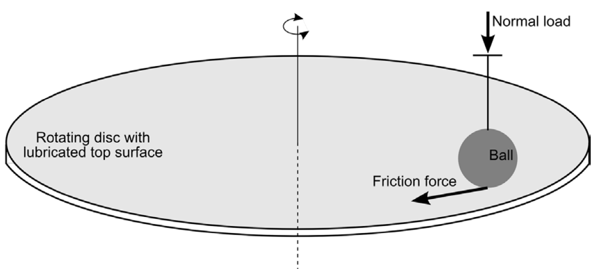

Fig. 1. Scheme of the ball-on-disk experimental setup.

3. Finite-element-based modelling approach

A general framework for the modelling of soft-EHL problems in the finite deformation regime has been developed by Stupkiewicz and Marciniszyn [1, 2], and this framework is adopted in this work. The finite element model of an EHL problem involves the fluid part, the solid part and the elastohydrodynamic coupling. The fluid part is conveniently modelled using the classical Reynolds equation. In the classical EHL theory, the solid part is usually modelled using the linear elasticity framework and an elastic half-space approximation. A distinct feature of the present approach is that the finite deformation effects are consistently treated.

The solid part is modelled using the finite element (FE) method so that an arbitrary (hyperelastic) material model and an arbitrary geometry can be analyzed. The Reynolds equation is formulated on the contact boundary of the solid and is discretized using the finite element method. The solid-fluid coupling (lubricant film thickness depends on the deformation) and the fluid-solid coupling (the hydrodynamic pressure and the shear stress are applied to the body as the surface traction) are fully accounted for. The Reynolds equation is formulated in an Eulerian frame which introduces an additional coupling due to the finite configuration changes.

The resulting nonlinear finite element equations are solved monolithically for all unknowns, i.e., displacements of the solid, lubricant pressures, and also other quantities, such as Lagrange multipliers, depending on the specific problem and specific formulation adopted. The nonlinear FE equations are consitently linearized so that the Newton method can be efficiently used. The model employs a recently developed mixed formulation of the mass-conserving cavitation model, see [3]. This formulation is particularly suitable for the specific mesh refinement technique used in the computational model. Mesh refinement is a crucial element of the finite element model because adequate description of the EHL coupling requires locally a very fine mesh. This is seen in Fig. 2a which shows the finite element mesh used to solve the problem of a hyperelastic ball sliding against a rigid surface in the hydrodynamic lubrication regime. Finite deformations of the ball are clearly seen in the Fig. 2b.

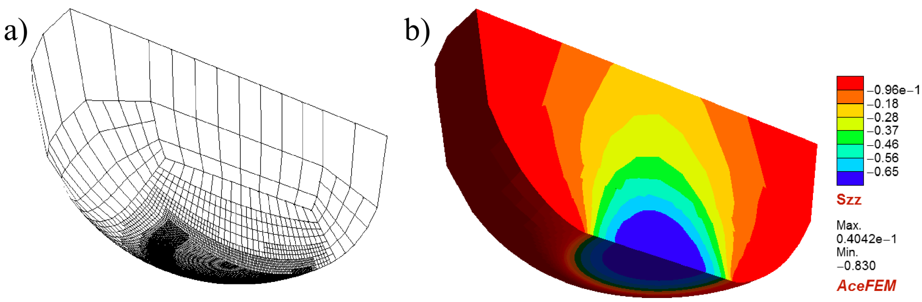

Fig. 2. Hyperelastic ball sliding against a rigid surface: a) undeformed mesh, b) distribution of σ_{zz} stresses (in MPa) in the deformed configuration [3].

References

1. S. Stupkiewicz, A. Marciniszyn (2009). Elastohydrodynamic lubrication and finite configuration changes in reciprocating elastomeric seals, *Tribol. Int.*, **42**, 615–627.
2. S. Stupkiewicz (2009). Finite element treatment of soft elastohydrodynamic lubrication problems in the finite deformation regime, *Comp. Mech.*, **44**, 605–619.
3. J. Lengiewicz, M. Wichrowski, S. Stupkiewicz (2014). Mixed formulation and finite element treatment of the mass-conserving cavitation model, *Tribol. Int.*, **72**, 143–155.