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Complementary scales and models to better describe lubricated contacts

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The good performance of mechanical systems, bringing into play moving relative surfaces, is conditioned by a suitable design of the contacts, potentially generating friction and wear. The usual technology to control these phenomena is lubrication.

In the last fifty years, remarkable progress has been made in order to build predictive models for lubricated contacts. This was possible because of the numerical resolution (more and more powerful) of the Reynolds equation, derived from fluid mechanics equations for very thin lubricant films. In this approach, most physical parameters (pressure, viscosity, density) are considered constant over the thickness of the lubricant. In some applications like the ball-on-inner ring contact in ball bearings, it is necessary to solve the deformation of the solids (postulated as elastic), while pressure, concentrated on a very small contact area, reaches the order of the gigapascal. Recently, an original method based on a Finite Elements Analysis was developed [1]. It allows a strong coupling between the solid deformation and the liquid flow on the solid boundary (where the contact occurs).

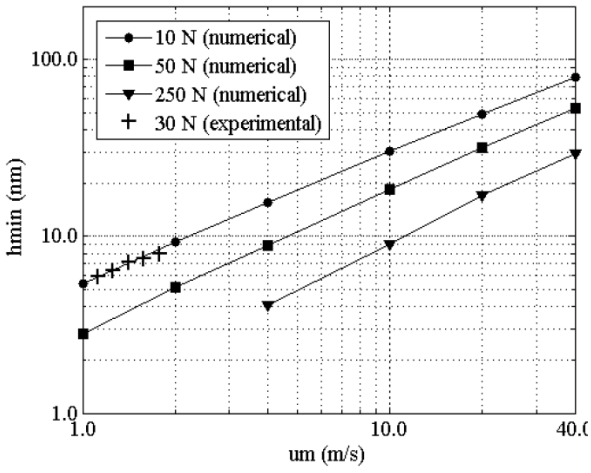

Fig.1 Orders of magnitude for minimum film thickness in lubricated contacts in nowadays industrial applications. From experimental and Finite Element approach in [1]

But this classical approach, based on continuum mechanics, shows its limit when applied to particularly severe conditions. Indeed, the current lightening of the structures and the environmental constraints take part in the use of ultra low viscosity lubricants which lead to film thicknesses of the order of the nanometer, meaning that only a few layers of lubricant molecules separate the solid surfaces. To investigate lubrication at the molecular scale, molecular dynamics simulations are run. From Thompson et al. [2] to Martini [3], many authors clearly show antagonistic behaviors (at this scale) compared to the predictions of continuous mechanics. Particularly, very dense layers of lubricant molecules are formed in the vicinity of solid surfaces, whereas the density is lower and nearly homogeneous in the center of the lubricant film. (see also fig. 2).

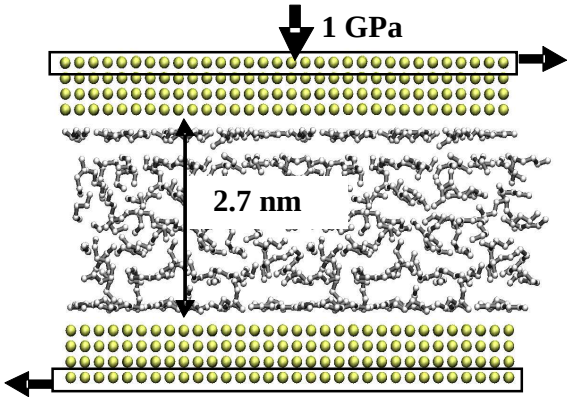

Fig.2 Snapshot of a 3D Molecular Dynamics simulation of an infinitely long lubricated contact (periodic boundary conditions). Surfaces: gold, lubricant: pentane.

According to the physical and chemical nature of the interactions between fluid and solid, interfacial slip can occur, which is completely neglected in the traditional approaches (Reynolds assumptions). If this molecular-scale approach is (at the present time – and for long) unable to model the whole contact, it allows on the other hand a detailed description of local phenomena responsible for macro-scale friction.

These two approaches exhibit very different but complementary phenomena. A discussion is then proposed to determine how physics studied from one scale can be integrated into another scale model.

[1] Habchi, W., "A full-system Finite Element approach to elastohydrodynamic lubrication problems: application to ultra-low viscosity fluids", Ph.D. thesis, INSA Lyon, Villeurbanne, France, 2008.
[2] Thompson, P.A., Robbins, M.O., Shear flow near solids: Epitaxial order and flow boundary conditions, Phys. Rev. A, 41, 12, 1990, 6830-6837.
[3] Martini, A., 2007, Molecular modelling and continuum analyses of thin film interfaces, Ph. D. thesis, Northwestern University, Evanston, Illinois, USA, 2007.