Soft lubrication: numerical theory & experiments

C. Putignano*

[1]Polytechnic University of Bari, Bari, Italy

Keywords: contact mechanics, lubrication, friction, pressure, film thickness.

Assessing the main peculiarities of lubrication between soft viscoelastic solids is a crucial issue that has only recently raised the attention of the lubrication science community. Indeed, in the last decades, massive research efforts have been dedicated to understanding the role of non-Newtonian lubricants, but very little has been done to determine what occurs when the lubricated solids are not linearly elastic and are instead characterized by a different rheology.

In this work, an innovative numerical methodology is presented to analyze the lubrication regimes between linear viscoelastic layers. In detail, an explicit finite difference scheme is coupled to a Boundary Element solver: this enables the study of the viscoelastic lubrication without any limitation in terms of material properties, geometry and viscosity. The results and, specifically, the film thickness, the contact pressure and, ultimately, the friction force show marked differences in comparison with classic lubrication theory. All this is validated by means of experiments specifically developed to deal with soft matter. In particular, to measure the film thickness, an innovative technique based on interferometry for soft solids has been employed.

To point out the main features of the proposed numerical approach, it is possible to focus on a simple problem: this is the description of the physics governing the lubrication of a rigid sphere in pure rolling over a one-relaxation-time viscoelastic half-space. For very low values of the speed, the deformable solid is in the elastic rubbery region and behaves, consequently, as a soft elastic body: no viscoelastic effect is present. When looking at the lubricating film, as expected, we observe an almost perfectly circular shape and, due to the flow conservation, a minimum at the fluid inlet can be observed. However, something different occurs when the speed is increased. Indeed, the contact zone gradually evolves towards a shape that is increasingly far from a circle and is affected by a sharp shrinkage at the fluid outlet. The contour plots of the fluid pressure clearly reveal a pressure peak that increases with the speed and produces, ultimately, a strong asymmetry towards the contact inlet.

The following step deals with the analysis of squeeze conditions, where the fluid is interposed between the rigid punch and a viscoelastic substrate. Results show the presence of pressure peaks at the contact edges and very peculiar trends for the central and the minimum thickness values. This confirms the necessity of ad hoc developed numerical methods for soft lubrication.