Relating stochastic roughness to friction in lubricated contacts

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Abstract:
The aim of our work is to understand the role of surface topography on the friction force for lubricated contacts. Since the friction force varies with different lubrication regimes (elastohydrodynamic, mixed, boundary), we focus on the way roughness shifts the transitions between these regimes, in terms of speed and load.

Mots clefs : lubrication, stochastic roughness, Stribeck.

1 Introduction

In most industrial applications, too much energy is dissipated into contacts between sliding surfaces. Most of these surfaces are machined by tools, which leave their print (rectification, milling) onto them. The resulting topography may, in most case, not be optimal for a durable tribological use. In order to reduce dissipation, our goal is to understand the role played by surface topography on a given lubricated friction experiment with realistic randomly rough surfaces.

Lubricated contacts in industrial applications are working on very different conditions, either in terms of loads, lubricant, speeds, surface roughness or materials. On the one hand, tribology attempts to reduce the wastes and expenses on the working point of industrial applications. On the other hand, one needs some tools able to get rid of the peculiarities specific to each one of these working points in order to identify the relevant physical mechanisms in each application. Regarding the surface speeds, the Stribeck curve is one of these tools.

2 Universality of the Stribeck curve and objectives

The Stribeck curve global shape is schematically presented in Fig 1 (dotted line). It exhibits three main lubrication regimes, meaning that the predominant physics that rule the friction change with the applied kinematic conditions. This should be a hint for a certain universality of the underlying friction mechanisms, irrespective of the nature of the lubricant, the chemistry of the surfaces, their mechanical properties or their history. Nevertheless, two Stribeck curves will differ by their friction levels and/or by the speeds at which the minimal friction is obtained.

We attempt to find how surface roughness shifts the transitions between the lubrication regimes and to identify a surface-inherent parameter likely to change significantly the evolution of a Stribeck curve.

3 Experiments

We perform sliding-rolling experiments at moderate speeds (10^{-3}-1 m/s) and pressures (0.1-1 GPa), for base oils of viscosity ranging from 0.001 to 1 Pa.s, on a disc-ball tribometer where both surface speeds are controlled independently and which is equipped with an interferometry system allowing the measurement of the lubricant thickness distribution into the contact (IRIS tribometer, LTDS). Before and after each rubbing experiment, ex-situ topographical measurements are performed on the surfaces using atomic force microscopy and interferometric microscopy, which allows to see possible surface evolution and to compute well-known stochastic quantities like the topography RMS roughness [1] or the mean summit curvature [2].

Several methods are used to change surface topography (DLC coating, polishing, machining, …) while keeping a disorder, which allow us to cover RMS roughnesses from the nanometric to the micrometric scale (see Fig. 2). But realistic processes do not permit to change topography varying continuously only one given statistical morphological parameter, clouding their effect into the contact. Moreover, many other effects like the fluid inertia [3], heating or lubricant rheology [4] have important consequences on the friction force.

To avoid further difficulties, we only use base oils without additives. Still, our experiments in fully flooded conditions display a pressure-dependent shear-thinning behavior of the lubricant [5], which might lead to wrong roughness-related explanations if one does not taken it into account.

4 Results on the mixed-elastohydrodynamic transition

Starting from high entrainment speeds and thick fluid films (~ 1 µm-thick), where roughness is unlikely to play a very important part, we implement a systematic methodology to measure the rheology of the pressurized lubricant. This allows us to predict the evolution of the friction force in elastohydrodynamic lubrication (EHL) until the onset of mixed lubrication (ML), i.e. when the countersurfaces asperities become close enough to each other to interact, thus rising the friction force. To the best of our knowledge, no scalar topographical parameter has ever permitted to build a master Stribeck curve for such random rough surfaces.

The Tallian criterion, which states that the ML starts occurring when the ratio between the film thickness and the RMS roughness becomes less than 3, works qualitatively well here. This supports the importance of the RMS roughness. Using Schipper's approach [6], we show that the transition entrainment speed at which the ML-EHL transition occurs roughly follows a power law towards the roughness arithmetical mean deviation (see Fig 3).

However, these approaches do not allow a precise prediction of the onset of the mixed lubrication. This is due to the lack of information contained into a roughness deviation parameter with regard to a friction problem. We will discuss the plausible roughness-induced scenarios that can occur such as elastic and plastic roughness deformation [7], local pressure increases, micro elastohydrodynamic lubricant entrapment [8] and partial boundary slip [9] to get a better understanding of the role played by surface topography in a lubrication problem.

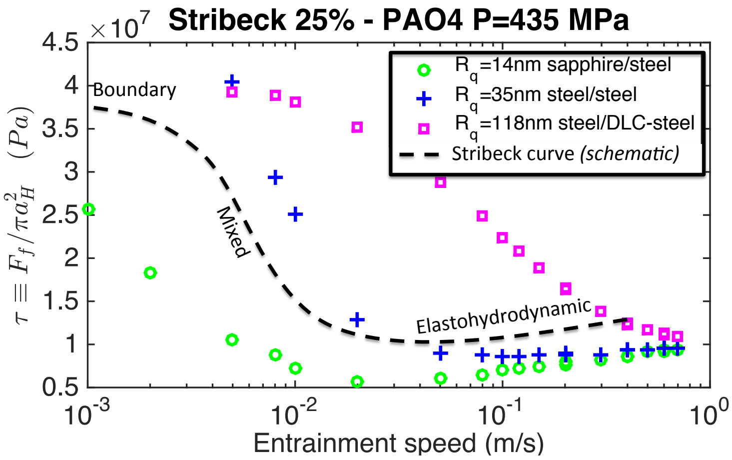

Figure 1 : Stribeck curves plotted as the measured shear stress plotted versus the entrainment speed (or mean surface speed), for different surfaces. One notices a generic shape whatever are the counter surfaces.

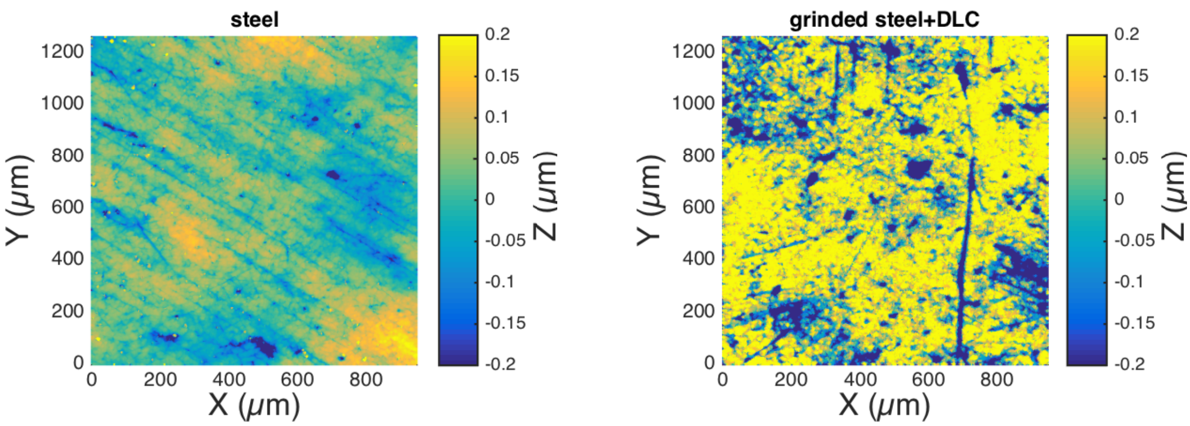

Figure 2 : Interferometric measurements of surfaces typically used in our sliding-rolling experiments. Steel disc (left) and a grinded-DLC coated steel (right).

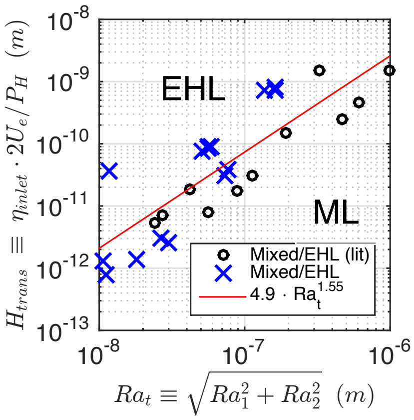

Figure 3 : Plot of the Schipper number H at the mixed-elastohydrodynamic transition vs the roughness arithmetical average of the surfaces. The (x) symbols correspond to our experiments, the (o) are data taken from [9].

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