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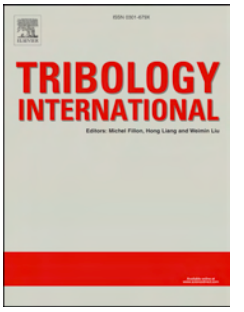

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Slipping domains in water-lubricated microsystems for improved load support

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Abstract

This work discusses the use of slipping domains to improve load support in water-lubricated microsystems through a multi-scale approach. A semi-analytical continuum formulation is developed to calculate changes in pressure distribution for a line contact with added slip. It is found that the slipping region maximizing hydrodynamic lift should favor inlet flow, but not be located at the contact outlet. Estimations for its positioning are provided. Slip on flat surfaces gives the largest gains in load support and friction reduction, but moderate improvements are also possible on circular geometries featuring high convergence ratios. Finally, Molecular Dynamics simulations are employed to quantify slip on hydrophobic surfaces. Among the considered topologies, graphene is an excellent candidate to generate slip in water-lubricated microsystems.

Keywords: Wall slip, hydrophobicity, microsystems, nanometer-thin lubricant films, hydrodynamic flow, Molecular Dynamics

1. Introduction

In the past decades miniaturization of technology has been applied to mechanical systems, biomedical applications, "lab-on-a-chip" analysis tools, sensors, and data storage. This trend has given rise to a new class of devices called Micro-Electro-Mechanical System (MEMS). Yet, from a tribological point of view, the usual problematic of friction and wear reduction is still present in this microscopic framework. For instance, stiction remains a critical issue [1]: due to large surface tension of capillary bridges and high adhesion, the contacting surfaces can stick together under operation. This phenomenon may lead to component wear and failure. A possible solution is to employ low surface energy coatings to reduce capillary forces, direct chemical bonding and electrostatic interactions between walls [2]. Such modification of the surface chemistry can for instance be achieved through deposition of hydrocarbon or fluorocarbon chlorosilane-based self-assembled monolayers (SAMs) [3, 4]. Additionally, one could reduce stiction by favoring hydrodynamic lubrication in the contact regions by the means of operating fluids already present in the system. An example is water, which is often found between MEMS surfaces due to condensation [1].

Interestingly, low surface energy coatings could be adapted to improve both direct surface contact and hydrodynamic lubrication. The underlying idea is that changes in surface chemistry may result in wall slip of the lubricant. This phenomenon is a velocity jump at a surface-fluid interface which contradicts the usual no-slip boundary condition in continuum fluid dynamics [5]. Its occurrence influences the lubricant dynamics across the film thickness, which can be exploited to tailor and enhance fluid transport in microfluidic applications [6, 7]. In tribological devices wall slip can be used to improve load support and reduce friction in the hydrodynamic regime, if applied only to a part of the surfaces. Possible benefits have been investigated numerically at the continuum scale through a modified Reynolds equation including slip boundaries [8, 9, 10, 11, 12, 13]. These studies have revealed that the enhancement of hydrodynamic lift is related to a modified pressure generation along the whole contact length, but can also be impacted by the occurrence of cavitation [14]. Moreover, load support was significantly increased when applying a slipping domain to parallel walls, compared to the optimum plane slider without slip [12]. Thus, most studies on heterogeneous

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