Compliant Boundaries: Microgel Coated Surfaces under Shear

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We have investigated the behavior of surfaces coated with dense layers of thermoresponsive pNIPAM-based microgels. We found that the stiffening of compressed microgels in the region of closest approach make it increasingly difficult to reduce the gap between the surfaces, limiting the contribution of microgels distant from the contact apex to the global friction. In dynamic conditions we observed the presence of shear-induced lift forces, which can be large enough drive the system from conditions of boundary to hydrodynamic lubrication. These findings suggest simple mechanisms for robust control of lubrication by properly tuning stiffness and geometry of the interacting bodies.
Keywords: soft contact, gel, elastohydrodynamic lubrication

1. Introduction

The great majority of surface force studies reported up to date have investigated relatively rigid objects. However, many systems of interest require a knowledge of the interaction between heavily compliant materials. For instance, most systems of interest in biotribology involve soft boundaries. In a typical contact of rigid bodies, only deformations close to the interaction zone must be considered. On the contrary, the shape of compliant bodies can change at much larger distances, and the long-range effect of surface forces must be considered. Interesting dynamic effects emerge also when shearing compliant objects. For instance, significant normal forces may emerge between soft bodies in relative motion, with important consequences in lubrication, e.g. in natural and artificial cartilages. This net repulsive pressure is associated with the symmetry breaking of the contact geometry under shear.

2. Methods

We investigated the interaction between mica surfaces coated by poly (N-isopropylacrylamide) pNIPAM-based cationic microgel by using an interferometric Surface Forces Apparatus (SFA). Normal separation and contact geometry were precisely measured by using multiple beam interferometry. Tribology experiments were carried out both at constant normal load and constant surface separation. Friction forces were measured while moving the surfaces at constant speed, using voltage-driven bimorph piezoelectric ceramics. The normal load was controlled by the deflection of a double cantilever spring attached to the lower surface. For the measurements performed at constant gap thickness, we have incorporated a feedback control loop based on the measured mica-mica separation at the point of closest approach during shear.

3. Discussion

3.1 Long-range repulsive interaction: limited surface approach
The long-range repulsive interaction between the coated surfaces engenders extensive deformation of the surfaces under load, limiting surface approach and severely restricting the growth of friction with compression, due to the difference in the range of action of normal and friction forces.

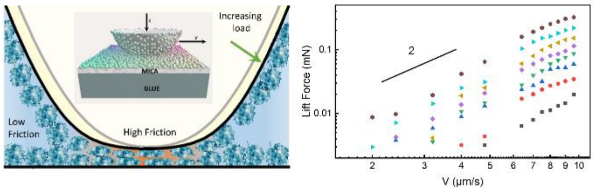

Figure 1: Schematic representation of the microgel-coated surfaces under load, and shear-induced lift force vs. driving speed at different imposed surface separations

3.2 Soft elastohydrodynamic effects
Shearing the surfaces coated by compliant layers can generate a lift force, triggering the entrainment of a fully developed fluid film at large enough speeds and minimizing the contact between the surfaces. After fluid film formation the system transits from boundary to hydrodynamic modes of lubrication. By using a feedback loop to fix the surface separation, we have been able to accurately determine this force, and to investigate its dependence on driving speed and surface separation. The scaling of the lift with these variables can be reasonably described by perturbative models developed to describe small dynamic deformations of the compliant coating.

4. References

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