Polymer-brush lubrication: How your artificial knee lasts longer

The desire to minimize friction between surfaces is as old as human civilization. While the architects of the Egyptian pyramids used water and sand, modern machine parts typically are lubricated by oil. Nature has found superior solutions. Mammalian joints, such as the human knee or hip, are subject to pressures of up to 50 atmospheres. They are lubricated by polymer brushes, which results in ultra-low friction that allows synovial joints to withstand a lifetime of wear and tear without the joint seizing.

Polymer brushes are comprised of polymer chains that are attached with one end to a surface. A polymer chain is a sequence of connected and repeating monomers, like the pearls of a necklace (Fig. 1). If the amount of polymers on the surface is large enough, the individual chains repel each other. This causes the attached chains to stretch away from the surface.

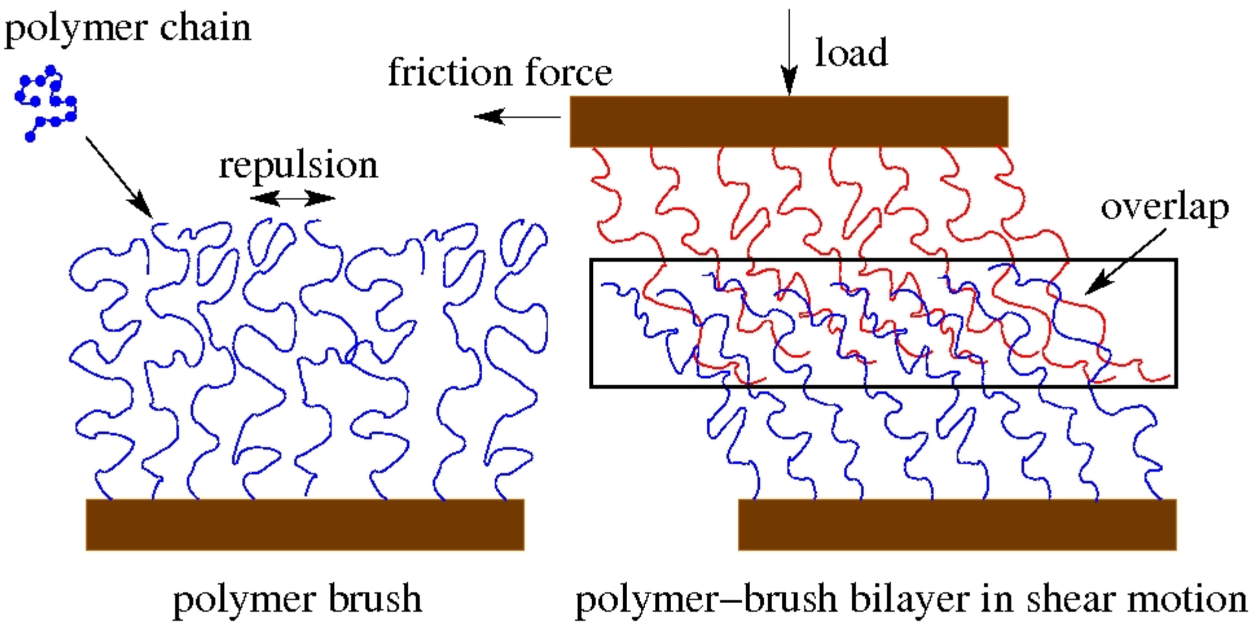

Fig. 1.

A system of two polymer-brush bearing surfaces pressed against each other is called a polymer-brush bilayer and has two remarkable features: The brushes offer strong resistance against compression (load) and, simultaneously, they display extremely small friction forces.

For strong shear motions, the chains can incline, which reduces the overlap between the brushes and thus the friction force. This is why polymer brushes are ideal candidates as lubricants in real and artificial joints. Currently, the lifetime of an artificial knee joint is approximately 15 years. Polymer brushes may extend the durability significantly and increase the life quality for many people.

Our theoretical model allows us to calculate the compressive forces (the load that the device carries) and the friction forces, yielding quantitative predictions for the friction coefficient. The latter is defined as the ratio between the friction and the compressive force and should be minimized to obtain good lubrication. Dry, non-lubricated surfaces typically have a kinetic friction coefficient of 0.1, while oil-lubricated surfaces have a value of approximately 0.01. Surfaces lubricated by polymer brushes can display a kinetic friction coefficient of 0.0001 or lower!

Nature does not use polymer brushes alone in joint lubrication. The synovial fluid contains macromolecular inclusions and charged macromolecules. Our research has found that such inclusions and electrical charge on the brushes (polyelectrolyte brushes) seem not to reduce friction, but rather prevent mechanical instabilities. The latter can occur, for instance, in form of an abrupt increase of the friction force, when the bilayer is subjected to a change of shear direction. This situation is typical for processes inside human knees or hips during walking, where the direction of motion is inverted many times.

As our theoretical understanding increases, we stand at the forefront of many exciting, new developments. For example, methods for switchable friction (changing from a super-lubricant to a strongly adhesive glue) or the usage of polymer brushes as sensors are being explored. In the future, polymer brushes should play an outstanding role in the field of smart materials and (already) find applications in artificial joints, chemical switches and sensors, self-healing surfaces, and so forth.

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Publication

Polymer-brush lubrication: a review of recent theoretical advances.
Kreer T
Soft Matter. 2016 Apr 21