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WATER-BASED BOUNDARY LUBRICATION WITH BIOMOLECULE ADDITIVES ON DIAMOND-LIKE CARBON AND STAINLESS STEEL SURFACES

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INTRODUCTION

Friction and wear incur high economic costs globally. It has been estimated that approximately 30% of energy is used to overcome friction. Especially in China huge part of the energy is produced by coal which causes severe pollution (Fig. 1).

Fig. 1. Pollution is a severe problem, especially in China. Picture taken in Suzhou Industrial Park in 2014.

To reduce energy consumption there are alternative ways. One way to reduce energy consumption is to develop low friction solutions. In mechanical engineering applications energy can be saved by developing new solutions, such as low friction coatings, surface texturing and lubricants (Fig. 2).

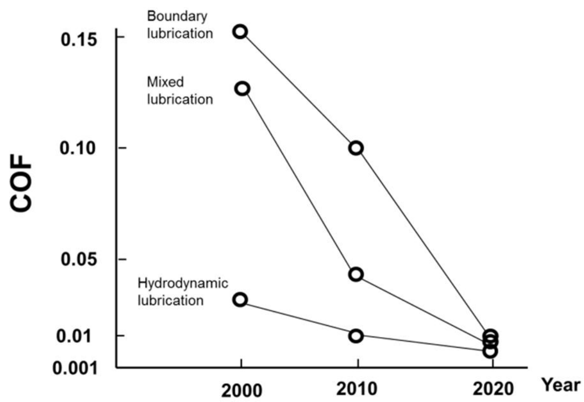

Fig. 2. The development of lubricants has reduced friction in different lubrication regimes, and this trend will continue in the near future (modified from Holmberg, 2012).

New lubrication solutions include new nano-additives and water-based lubricants. In this thesis, water-based lubricants with hydrophobin protein (HFBI, HFBII (Fig.3) and FpHYD5) and quince mucilage additives were used to lubricate engineering materials such as diamond-like carbon (DLC) coatings, stainless steels and plastics.

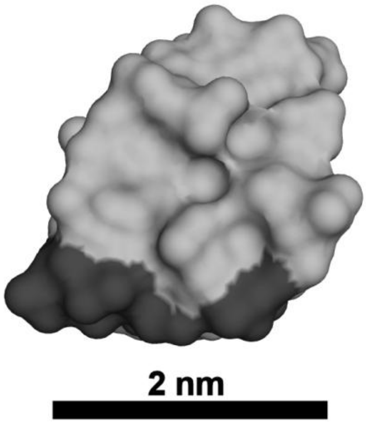

Fig. 3. Structure of an HFBII hydrophobin protein. The light grey colour indicates the hydrophilic-exposed surface and the dark grey colour at the bottom indicates the hydrophobic patch. The diameter of the hydrophobic patch is approximately 2.2 nm. (Structure from Protein Data Bank entry 1R2M; Hakanpää et al., 2004)

Low friction in biomolecule-lubricated contacts is usually achieved by hydration lubrication. In hydration lubrication, the sliding occurs between the hydrophilic parts of the two molecule layers that are adhered to both sliding surfaces, and low friction is related to the bound water and its fluidity (Klein, 2004).

RESULTS

It was found that hydrophobins can form monolayers on stainless steel, diamond-like carbon (a-C:H) and PDMS surfaces (Fig. 4). On stainless steel surfaces, HFBI and FpHYD5 layers contain 40-64% water. The amount of adhered hydrophobins on stainless steel and diamond-like carbon surfaces was affected by the pH of the solution.

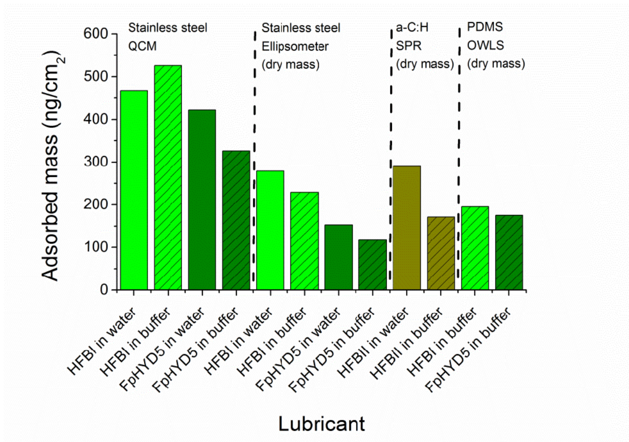

Fig. 4. Adsorbed mass of hydrophobins on different surfaces. Ellipsometer, SPR and OWLS measure the dry mass of hydrophobins adsorbed on the surface while QCM takes bound water into account (Publications II and V; Hakala and Lee, 2011).

Increase in amount of adhered hydrophobins increased friction in stainless steel vs. stainless steel contacts. However, increasing the water content in hydrophobin film reduced friction in stainless steel vs stainless steel contacts. The same effect of water content was seen in quince mucilage-lubricated UHMWPE vs stainless steel contact. Quince mucilage-lubricated UHMWPE vs stainless steel reduced the friction coefficient to as low as 0.02. Of all the tests, the lowest friction coefficients (close to 0.01) were measured with HFBI and FpHYD5 hydrophobins in PDMS vs PDMS contacts (Fig. 5).

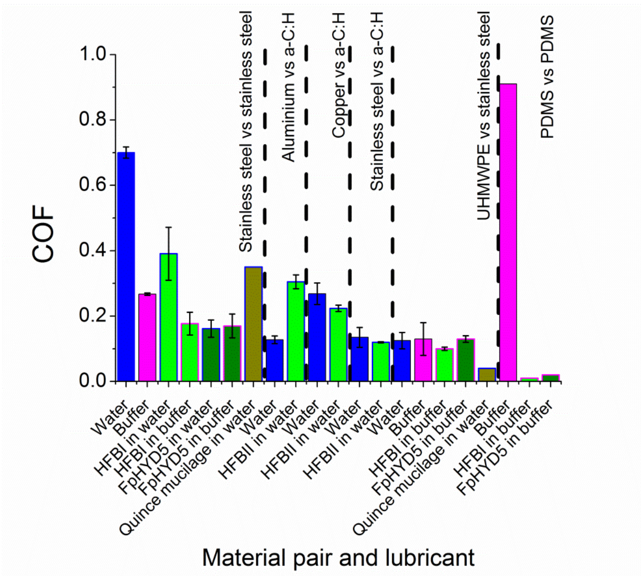

Fig. 5. Lubrication of different material pairs with water, 50 mM sodium acetate buffer, hydrophobin proteins and quince mucilage. (Publications I-VI; Hakala and Lee, 2011)

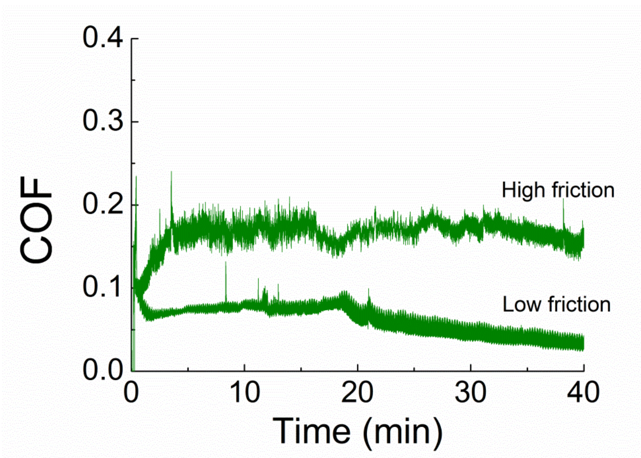

Fig. 6. Two friction curves measured in a stainless steel vs stainless steel POD experiment. Although the conditions were identical, the friction was significantly lower in the second experiment. The contacts were lubricated with FpHYD5 in 50 mM acetate buffer. The test parameters were normal load 10 N, sliding velocity 0.1 m/s and duration 40 min.

The lowest friction coefficients in stainless steel vs stainless steel contacts were measured in FpHYD5 lubricated contacts where COF as low as 0.03 was measured (Fig. 6). Low friction was related to protein film formation on the wear track of the stainless steel ball (Fig. 7).

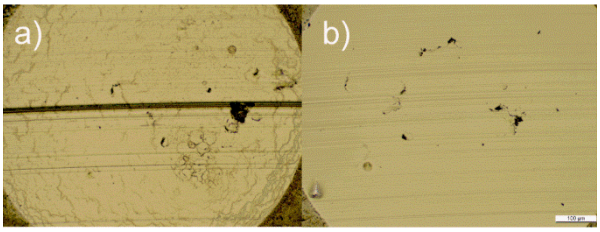

Fig. 7. a) Tribofilm formed on the stainless steel surface, b) no tribofilm formed.

DISCUSSION

Requirement for hydration lubrication mechanism is that the sliding occurs between molecule layers. It can be assumed that this is the case when contacts are lubricated with hydrophobin proteins. Low friction in hydrophobin-lubricated contacts occurred when both sliding surfaces had molecule layer. Such situations were met when tribofilm of hydrophobin proteins was formed on stainless steel ball and in PDMS vs PDMS contacts were hydrophobins covered both sliding surfaces (Fig 8).

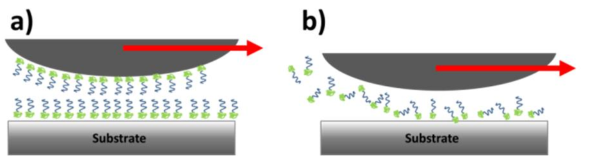

Fig.8. a) A situation in which hydration lubrication is possible in a POD experiment, b) a situation with hard materials in which wear and shear force have removed molecules from the upper surface, which is constantly in contact.

CONCLUSIONS

Based on the results, it can be suggested that the requirements for water-based lubrication with biomolecule additives in industrial applications are

- A mild temperature range that is suitable for water lubrication and biomolecules, T= 4 - 95°C
- Low contact pressures, 0.1-5 MPa
- Hydrophobic surfaces, contact angle of water >90°
- Stable conditions (pH, ionic strength)

In the future, water-based lubricants could be used in, among others, the food and beverage industry, the textile industry and biomedical applications.

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