【Grant-in-Aid for Scientific Research (S)】

Science for Boundary Lubrication - Essence of Low Friction Mechanism Based on Structure and Dynamics of Additive Adsorption Layer

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Project Information	Project Number : 23H05448 Project Period (FY) : 2023-2027 Keywords : Mechanical engineering, Machine elements, Tribology, Lubricants

Purpose and Background of the Research

●Outline of the Research

In recent years, the demand for friction reduction on sliding surfaces of machines and expectations for the field of tribology have been increasing in order to realize a more energy-efficient society. In this study, we focus on the **"boundary lubrication layer"** derived from the surface adsorption of additives contained in lubricating oil, and aim to predict its friction coefficient and provide optimal design guidelines for further ultra-low friction. Specifically, the origin of the formation of the boundary lubrication layer is determined as the dissolution of additive molecules in the base oil, adsorption on the surface, and dynamics of the molecules in the base oil. The structure and physical properties of the boundary lubrication layer in the base oil are extracted. Furthermore, we aim to clarify the essence of boundary lubrication for the development of ultra-low friction by connecting **the structural and physical properties** with the **"principle friction coefficient of boundary lubrication"** in "point" and "surface" contact systems with the aid of molecular simulations. By shedding light on the "boundary lubrication", which has not been approached except by conducting friction tests, and by systematizing it as a science, we aim to create a new science of "boundary lubrication".

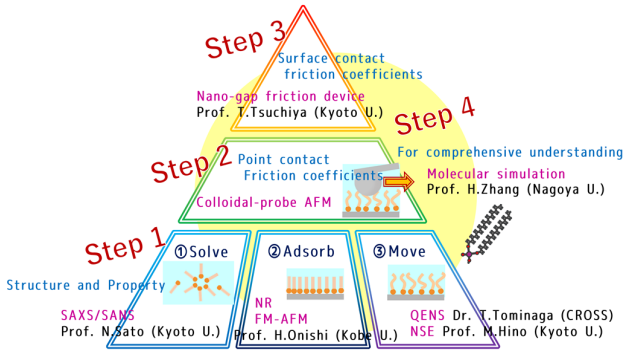


Fig.1 Outline of our research

●What is "Boundary lubrication layer"?

In the boundary lubrication condition, the existence of some soft layers, commonly called **"boundary lubrication layers"**, formed on solid surfaces is considered key, and there has been much discussion regarding the structure and formation mechanisms of these layers. In general machines, the source of the formation of such boundary lubrication layers is mainly **"additives"** mixed in the lubricating oil.

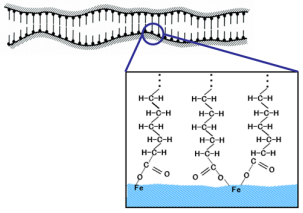
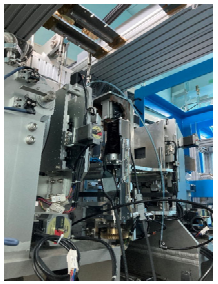


Fig.2 Hardy's boundary layer model

●Main Features of the Research

- There have been no previous researches to clarify the structure and physical properties of boundary lubrication layers, from the viewpoints of additive dissolution in base oils, lubrication layer formation, and dynamics, and to elucidate the friction reduction mechanism.
- This proposal is highly unique because it is made possible by combining the *operando* quantum beam analysis and knowledge of tribology accumulated by our group.



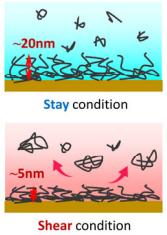


Fig.3 Neutron reflectometer with tribometer with nano-gap under shear

Expected Research Achievements

●Purpose of the research and how to proceed

This research aims to systematically link the structure and physical properties of the **boundary lubrication layer** in base oils to the **"coefficient of friction of boundary lubrication"**, to predict them and to provide design guidelines for boundary lubrication layers that can lead to even lower friction. The objective of the research is to shed light on the **"boundary lubrication phenomenon"**, which has not been approached except by conducting friction tests, and to systematize it as a science to clarify the essence of the **"boundary lubrication phenomenon"** derived from the adsorption of additives in lubricant. As a concrete approach to achieve this, this study will take the following four steps.

Step 1 Understanding the Structure and Physical Properties of Boundary Lubrication Layer under tribological conditions
- ① Solve Structural analysis of additive molecule in lubricant by SAXS/SANS
- ② Adsorb Structural analysis of boundary lubrication layer by NR and FM-AFM
- ③ Move Dynamics of molecules of boundary lubrication layer by QENS/NSE

Step 2 Principle friction properties of boundary layers in "point" contact

Step 3 Principle friction properties of boundary layers in "surface" contact

Step 4 Prediction of boundary lubrication friction coefficient and presentation of optimal design guidelines for boundary layer for ultra-low friction

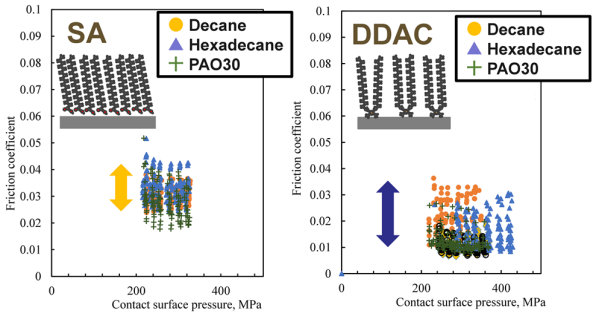


Fig.4 Example of relationship between molecular structure and friction coefficient of boundary layers

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