Friction and Wear

The datasheet for DIN 50281 (Deutsches Institut für Normung, or German Institute for Standardization) describes the term "Reibung" (friction) as follows: "The resistance that occurs on the surfaces of contact between two bodies that impedes mutual motion, or even makes it impossible, is called 'friction.'"
Distinctions are made among three types of kinetic friction of solid bodies: rolling friction, sliding friction, and rotating friction. When there is friction, wear begins directly on the material. For that reason, wear on kinetic artworks often calls for a compromise between the demands of the physical preservation of the object and its function in the form of movement. To reduce wear in areas with large erosion of material, it is useful to add wear layers that reduce the material loss of both partners in the friction. Solid bodies such as plastic, metal, or wood can be applied as sacrificial substances that slow the prevent of the original material. With the aid of lubricants like greases, oils, or solid lubricants, by contrast, improves already existing friction situations.
Greases and oils in museum collections tend, on the one hand, to spread uncontrolled over surfaces and, on the other, to attract dust. For both these reasons, a wear layer employing solid bodies should be considered before treating with oils and greases.
In the scholarly literature on restoration, EGGER mentions the use of inlays of epoxy resin with iron fillings or aluminum powder in places particularly susceptible to wear, where steel rubs on steel and where wear is already advanced, for example.[1] In the Museum Tinguely a similar experiment is being carried out in which a layer of epoxy resin without additives is applied directly to the work. At the time of publication this cast inlay has already stood up to two years of exhibition. A further experiment will consider the addition of graphite and other materials not prone to alter color or strength.

[1] EGGER 2002, pp. 42,43.

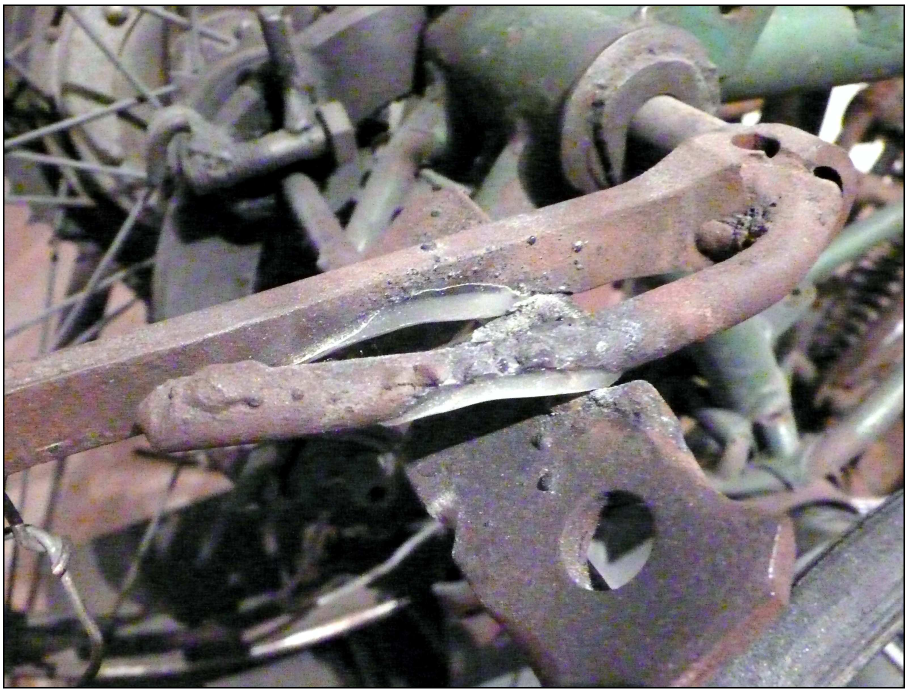

Fig. 1: Wear Layer of Epoxy Resin on a Pedal with High Friction after Two Years on Exhibition

The Museum Tinguely continues to have favorable experiences with applying overlays made of, for example, wood that absorb the entire force of the friction.

If operation and the reduction of wear require the use of a lubricant, the following overview offers information about the common materials, their composition, and their advantages and disadvantages. The data are largely derived from Steffen Seidel thesis on lubricants in restoration.[2] Raw materials for oil lubrication include standard commercial basic oils such as mineral oils, ester oils, and silicone oils. To these oils are added, depending on the application, thickeners such as lithium soap, polyurethane materials, calcium complex soap, aluminum soap, or barium complex soap are added, which thickens the oil and forms a grease. Requirements for lubricants can include: low temperatures by high rotation, good sealant properties against water or dampness.

Petroleum-based Lubricant Oils

Of the aging behaviors of petroleum-based SEIDEL remarks, simplifying somewhat: "As the molecular weight of the hydrocarbons increases, the melting and boiling points reach higher temperatures. Hence as the length of the chains increases, viscosity and the solidification point increase as well. All hydrocarbons possess very low corrosivity and hence are very compatible with metals. Because compounds with double bonds react better with oxygen than molecules with single bonds, paraffins and naphthenes are more resistant to oxidation than olefins and aromatics. Naphthenes and aromatics are most resistant to heat,

[2] Seidel 2001.

since hydrocarbon chains like paraffins vibrate more in response to heat, which can lead to the breakdown of the molecule."[3]

"The resistance of mineral oils with thickening materials is dependent on the aromatic content. As aromatic content increases, attacking does as well. The higher the viscosity and temperature, the more pronounced the swelling effect. Paraffin hydrocarbons, by contrast, can shrink or harden elastomers."[4]

Synthetic Fluids

"In contrast to mineral oils, synthetic oils consist of uniformly structured, defined compounds whose properties can be adapted to the area of use. In general, synthetic oils are not very sensitive to temperature in terms of viscosity and exhibit favorable behaviors in response to cold, heat, and wear. There is, however, no single synthetic fluid that unites all of the advantages over mineral oils. Rather, the advantages are always paired with disadvantages."[5]

Synthetic Hydrocarbons

According to SEIDEL this group of materials is most often found as polyalphaolefins. "They represent an ideal basic oil, which is used primarily as a motor, gear, and bearing oil. But many lubricants of tribological[6] systems intended for long life are based on this basic oil. They are among the oils that do not cause elastomers to swell but tend rather to shrink them. In addition, they are distinguished by excellent oxidation stability and thermal resistance."[7]

Polyglycol

According to SEIDEL, these materials display unfortunate reactions to common sealants, are aggressive to single-component lacquers, and not very resistant to oxidation, so they are not recommended as lubricants in museum collections.[8]

Ester

According to SEIDEL, "Carboxylic acid esters and phosphoric acid esters and are employed as flame-resistant lubricants. . . . They possess very good oxidation and thermal resistance. . . . Dicarbonic acid esters, by contrast, are aggressive against many metals and plastics."[9] It is difficult to predict the interaction of the various esters with other materials, so their use in museum collections is not advisable.

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[3] SEIDEL 2001: pp. 60–61.
[4] SEIDEL 2001: p. 62.
[5] SEIDEL 2001: p. 63.
[6] Tribology: Subfield of the technical sciences concerned with friction between surfaces moving relative to one another and the associated effects such as wear and heating.
[7] SEIDEL 2001: pp. 64–66.
[8] SEIDEL 2001: pp. 66–67.
[9] SEIDEL 2001: pp. 67–69.

Silicone Oils

According to SEIDEL, these oils "are highly compatible with metals, plastics, and rubber. . . . They are very resistant to chemicals, are not water-soluble, and because of their nonpolar structure they do not react. They scarcely absorb UV and gamma rays at all. Silicone oils are good lubricants for systems subject to rolling friction. By contrast, when subjected to surface compression (slide bearings) they are of limited use because of the limited pressure tolerance (shear stability). Their lubricating effect is dependent on the existing pairings of materials. Plastic-plastic and plastic-metal combinations can be lubricated well. With steel-steel combinations their uses is limited because of poor adsorption and limited surface tension. . . . Silicone oils are considered physiologically harmless because of their inertness. One disadvantage of using silicone oils is their limited surface tension, which is why silicon oils offer limited rust protection. Silicone oils are used for precision parts like speedometers, clocks, and instruments and for lubricating plastic parts."[10]

Lubricating Greases

"Lubricating greases belong among the consistent lubricants and are the result of thin distribution of a thickener in a fluid lubricant. Despite their homogenous external appearance, they consist of a number of various, largely organic bonds. They can be summarized in three main components, according to their proportional quantity, as follows":[11]

- base oil 65–95 percent of mass
- thickener 5-25 percent of mass
- additives 0–10 percent of mass

The most common classical greases can be divided into the following types:

- lithium soap greases have limited water repellence and, when combined with additives, are oxidation-resistant.
- soapless greases have inorganic or organic swelling agents. They are employed for extremely aggressive chemicals.
- calcium soap greases are particularly water-repellent, shear stable, and respond well to cold.
- sodium soap greases emulsify with water and prevent corrosion.

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[10] SEIDEL 2001: pp. 70–72.
[11] SEIDEL 2001: p. 73.

Base oil

"Liquid lubricants represent the major component of greases. Here the desired properties of both the grease and the mineral or synthetic oil come into play. The majority of greases produced today using mineral oils as their base oil. Greases based on synthetic oils are employed primarily in special fields, such as those subject to particularly high or low temperatures."[12]

Thickener

"The thickener is the second largest component of greases, and they are fundamentally responsible for the structure of greases. . . . For example, because they are water-soluble, sodium soaps are less suited than to greases than lithium soaps are. The later are the most commonly used greases today. Lithium soap greases show favorable water and mechanical resistance and can be used at temperatures up to 120° C. They are therefore common as multipurpose greases."[13]

Additives

Because of the wide range and complexity of this field, the reader is referred to SEIDEL's thesis for additional information. To give a sense of the wealth of additives, we merely list their various types: oxidation inhibitors, radical catchers, peroxide decomposers, corrosion and rust protection additives, extreme pressure or antiwear additives, detergent dispersant additives and additives for peptizing, solubilization, neutralization, viscosity index improvers, pour-point reducers, friction modifier, and foam inhibitors.

Solid Lubricants

Solid lubricants are a sensible complement to conventional lubricants like greases and oils. They are necessary when greases and lubricating oils can no longer fulfill their function. Solid lubricants reduce friction and wear while also protecting against corrosion. The best-known solid lubricants are graphite, molybdenum disulfide, tungsten disulfide, and polytetrafluoroethylene. The basic materials and the additives also determine the appearance of the lubricants. Greases containing graphite or molybdenum disulfide are always dark or black. Hence bright, white, and cream-colored lubricants contain only additives that work chemically.
"Solid lubricants. . . . can be divided into three major groups: those that work by chemical reaction, those that work physically, and those that work structurally."[14]

[12] SEIDEL 2001: p. 73.
[13] SEIDEL 2001: p. 74.
[14] SEIDEL 2001: p. 77.

Lubricants That Work by Chemical Reaction

"The group of solid lubricants that works by chemical reaction includes various hydroxides, carbonates, and phosphates, such as calcium diphosphate, copper diphosphate, and calcium carbonate. The effectiveness of these materials is based on the formation of very tightly bonded layers by reaction with iron.

These materials can be applied in the form of pastes, suspensions, or greases."[15]

Lubricants That Work Physically

"The group of solid lubricants that works physically includes various metal bonds, films, powers and polymers. Metal films of lead, silver, gold, and copper can be used to reduce friction. These layers can be applied by means of vacuum evaporation or by galvanization on a hard metal surface. The low shear stability of such materials means that the sliding property of a frictional system can be improved. Polymers such as polytetrafluorethylene, for example, have good sliding properties. The limits of application for these materials are essentially determined by their thermal, mechanical, and chemical properties."[16]

The solid film lubricants available commercially number among the lubricants that work physically. They are a suitable alternative for high surface pressure with low sliding velocities.

Lubricants That Work Structurally

"The most interesting group is made up of lubricants that work structurally, the most important of which are graphite and molybdenum disulfide. The lubricant effect of these materials is based on the layered lattice structure of their crystals, which enable them to absorb a great deal of pressure vertically to the layer as well as shifting to the side parallel to the layers.

Molybdenum Disulfide

Molybdenum disulfide has a platelike structure whose lattice form is made up of three layer: two layers of sulfur with a molybdenum layer between them. Whereas the sulfur and molybdenum atoms form strong valence bounds (atom bonds), the two sulfur layers are bound by weaker Van der Waals forces. These two binding forces are crucial for the physical effect of this lubricant.

Molybdenum disulfide is chemically and radioactively stable, though it is corrosive on iron and steel in the presence of water. As pressure and speed increase, the sliding properties in tribological systems decreases.

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[15] SEIDEL 2001: p. 77.
[16] SEIDEL 2001: p. 78.

Graphite

Graphite has a structure similar to that of molybdenum disulfide and hence has identical physical properties. The effectiveness of this lubricant is, however, dependent on the presence of an absorbed film of gas, oil, or water. Its effectiveness as a dry lubricant is limited.
Graphite is chemically stable and almost entirely insensitive to radiation. Its resistance to pressure increases with the temperature.
In summary it may be said that lubricants such as graphite and molybdenum disulfide that work structurally are characterized by very good resistance to aging and the best resistance to aggressive mediums. The use of solid lubricants is most effective in areas where liquid lubricants cannot be used because of the circumstances of operation or surroundings. The lattice structure and the smoothing of frictional surfaces by being taken up between peaks of roughness makes the frictional partners in tribological systems more reliable.
Lubricants can be applied by forming a direct film by means of powders, solid film lubricants, or pastes or by indirect formation of a film by means of colloidal solutions in oils and greases. Disadvantages include continuous abrasion when the parts are not lubricated subsequently, especially in the case of direct formations of films; greater loss to friction from dry friction; and lack of corrosion protection."[17]

Summary

When the use of lubricants for a work is unavoidable, and a selection has to be made, the information summarized above can provide an overview of this large field of materials. It will, however, be indispensable to ask the manufacturers about suitable materials and to find a solution in an exchange with them. "For ultimately, in addition to the type of base oil, the properties of the finished lubricant in combination with the circumstances of operation anticipated are significant. It does not help, for example, if the available chemical tolerance results in a viscosity too low for the implementation desired."[18]

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[17] SEIDEL 2001: S.78-80.
[18] I am grateful to Steffen Seidel for pointing this out to me in an e-mail in January 2007.