Understanding Solid Film Lubrication

In High-temperature Applications

Glaze-forming solid-film lubricant technology was originally developed by the National Aeronautics and Space Administration (NASA) for the space shuttle program as a means of providing a journal bearing lubricant that works in an oxygenated atmosphere, in a vacuum, and functions at temperatures encountered during re-entry. The lubricants developed contain lubricative oxide material (LOM) particles that are self-lubricating in any atmosphere, as well as in a vacuum and at high environmental and frictional temperatures.

The novel aspect of this technology is that the lubricants also contain glaze formers that help to bond the solid film to the substrate and create a new lubricated wear surface on top of the substrate. Many areas in industry can utilize this technology to solve difficult high-temperature lubrication and wear problems.

Glaze-forming solid-film lubricants create a new surface, approximately 30 microns (0.001-inch) thick, on the bearing surfaces and fill in small surface irregularities. The new surfaces are formed on both contacting surfaces of the bearing (for example, shaft outer diameter and journal inner diameter). The new surface is smooth, nonmetallic, possesses a low coefficient of friction and provides corrosion protection to the substrate. During motion between the shaft and journal, the glaze wears away, but the metal surfaces remain unaffected. The glaze is periodically replenished to maintain lubrication and prevent metal-to-metal contact.

Cer-Oxi FilmTM high-temperature compound is a paste-like compound composed of a synthetic base oil, LOMs, glaze formers and proprietary materials. NLGI #00, #0 and #1 consistencies are pumpable through central distribution systems or can be dispensed from a grease gun for reapplication, depending upon the configuration of the specific application. These compounds are used to lubricate plain journal bearings and sliding surfaces. They are not suitable for antifriction element bearings (ball and roller bearings).

Figure 1. Thin Layer of Wet Lubricant Compound on Shaft Surface

Glaze Formation at the Macroscopic Level

A 125-micron (0.005-inch) layer of the paste-like solid-film lubricant compound is applied to the sliding surfaces of a steel shaft (Figure 1). This can be performed without disassembling the equipment via a common centralized lubrication system or a grease gun, depending on the application.

When the coating is subjected to temperatures exceeding 315°C (600°F), the base oil volatilizes leaving a dry, powdery coating on the shaft surface.

During service, the powdery coating must be subjected to high environmental temperature, high contact pressure and high frictional temperature (generated by motion between the two contacting surfaces) for the glaze to form (Figure 3).

The glaze is a thin, shiny, smooth, slippery nonmetallic layer tightly bonded to the substrate. The glaze is the desired effect, and shows that a new wear surface has been created.

Figure 2. Dry, Powdery Lubricant Film After Heating

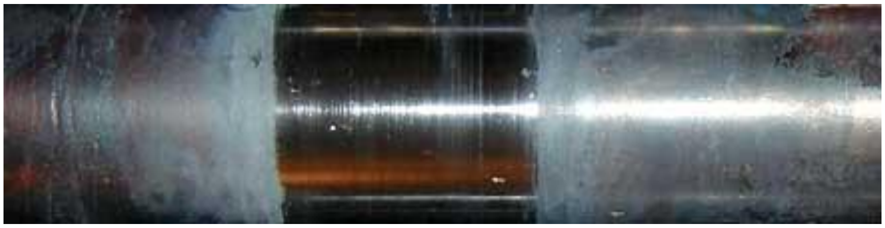

Figure 3. Glaze Formed by Solid-film Lubricant

Glaze Formation at the Microscopic Level

At the microscopic level, all machined surfaces consist of microscopic, mountain-like asperities, plateaus and valleys. The formation of a solid-film lubricant glaze takes place at the microscopic level as the asperities or plateaus of the opposing surfaces collide and slide over one another.

When the surfaces are coated with the CerOxi film compound, a thin film of carrier fluid and nano-size solid lubricant particles coat the asperities, plateaus and valleys of the mating surfaces. As these surfaces come together, the carrier fluid keeps the surfaces apart through elastohydrodynamic fluid pressure generated between the mating surfaces.

When asperities and plateaus collide, frictional temperatures above 315°C (600°F) and Hertzian loading more than 200,000 psi occur instantaneously at the microscopic contact areas of the collisions. At 315°C (600°F), the carrier fluid completely evaporates leaving no residue. A soft, dry mixture of nanoparticles (powder) now coats the mating surfaces. (Figure 2).

The contact pressure and frictional temperature resulting from asperity and plateau collisions melt the powder nano particles, forming a thermo-chemical liquid that lubricates the mating surfaces (as long as the frictional temperature remains high). When the contact surface cools, the liquid solidifies into a solid oxidation-resistant glaze bonded to the substrate.

The new coating material diffuses into the substrate for additional wear resistance, provided relubrication occurs to maintain a supply of lubricant to the mating surfaces. For applications where the temperature remains above the boiling temperature of the carrier fluid, novel methods of applying the lubricant would have to be developed, such as spraying a dry powder form.

Figure 4. Graphite Grease-lubricated Surface of Wheel After Exiting Furnace

Case Study

Consider this example of high-temperature axle lubrication at Mittal Canada Hamilton Inc. Coils of steel rod, bar and wire are carried through a controlled-atmosphere annealing furnace on flat, stainless trays. Each tray has three rows of wheels that roll in channels running the length of the furnace. The wheel and wheel axle consists of a stainless-steel casting, and the mating axle journal is also cast stainless-steel.

The maximum temperature in the furnace is 750°C and time in the furnace ranges from eight to 24 hours. The axles rotate in a plain journal as the trays move through the furnace. The axles were lubricated with graphite grease daily. The temperature upon exiting the furnace is above 200°C and the warm trays can be exposed to air for up to one hour before re-entering the furnace.

Lubrication failure can result in galling and seizing of the axle, which increases the force needed to move the load. Occasionally, seized axles lead to a furnace jam, where the trays could not be moved by the pushing equipment. The furnace had to be shut down, cooled, cleaned out and all damage repaired. The result is a significant equipment and production outage.

Solid-film lubricant technology was found to be the only lubrication method capable of handling the temperatures inside the furnace, and was chosen to replace graphite grease for lubrication of the axle and journal bearing surfaces.

The bearing surfaces lubricated with graphite grease are oxidized and rough (Figure 4) after exiting the furnace. The coefficient of friction for this surface is 0.332. The solid-film lubricant compound is squirted in the gap between the axle and journal with a grease gun by the furnace operator. A new surface is created as the compound passes through the furnace and forms a glaze on the mating surfaces (Figures 5 and 6).

Figure 5. Glazed Axle Surface

The surface pressure, furnace temperature and frictional heat generated by the sliding surfaces convert the compound to a dark, smooth, slippery, glazed solid-film coating 30 microns thick. The coating is chemically bonded to the surface substrate. The coating fills in surface irregularities; levels the micro surface; and creates smooth, slippery, low-friction contacting surfaces (Figure 6). The coefficient of friction between the glazed surfaces is 0.192.

The glaze also prevents the coated surfaces from oxidizing while the trays are at elevated temperatures outside of the furnace.

The compound transfers to the mating surface and forms a glaze on that surface as well. The low frictional force and low wear rate are the result of two glazed surfaces containing solid lubricant particles moving over each other.

Figure 6 shows that a glaze forms on the mating surface and that the glaze is located at the point of highest contact pressure. Because not all of the journal surface sees high contact pressure, a uniform glaze is not expected to form on the whole journal surface. In this case, the load on the journal is applied vertically at the 12 o'clock position, the point at which the glaze has formed. The journal was turned upside down for the photo.

The solid-film lubricant coating reduced the coefficient of friction between the axle and journal by 42 percent, thereby reducing the force required to move trays through the furnace and the load on the pushing equipment.

A fully established solid-film lubricant coating provided 22 days of continuous (24/7) production before the frictional force between the axle and journal reached the level at which relubrication is recommended. The wear rate of the solid film coating is low, allowing long intervals between relubrication.

Figure 6. Glazed Journal Surface

Benefits

The benefits realized by Mittal Canada Hamilton include the following:

1. Less furnace downtime caused by wheel lubrication failure, resulting in increased production time.
2. Eliminated the high cost of repairing the furnace damage resulting from a furnace jam because wheel axle seizing no longer occurs.
3. A significant reduction in tray replacement costs due to reduced wear and damage to furnace trays.
4. Reduced wear and maintenance on the pushing equipment and wheel channels inside the furnace because the force required to move the load is lower.
5. Relubrication cycle extended from daily to once every three to four weeks, leading to:
    a. Lubricant consumption by volume reduced by a factor of 20.
    b. Less contamination of the furnace atmosphere with carbon (from graphite grease).
    c. Improved worker morale by eliminating the daily messy greasing function.
6. The cost of a solid lubricant compound is less than 20 times that of graphite grease, resulting in an overall lubricant cost reduction.

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