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Novel surface treatment reduces friction and wear

Solid lubricants have proven to be very useful in reducing the friction and wear encountered by machinery under severe applications. This type of lubricant is required because conventional fluid-based lubricants cannot handle the extreme pressure and temperatures encountered.

Most solid lubricants are coated onto metal and plastic substrates. Examples of solid lubricants include graphite, molybdenum disulfide and polytetrafluoroethylene (PTFE).

One concern about solid lubricant coatings is the potential for them to wear off as the surface erodes over time. Such coatings can be subjected to chipping, flaking and peeling. If a process could be developed to incorporate the solid lubricant more effectively into the surface, then the resulting material could perform over longer operating intervals.

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Micro-alloy

STLE member Jane Buehler, chief technical officer for Kinetitec Corp., in Spokane Valley, Wash., says, "We have developed an innovative approach to incorporate the solid lubricant into the substrate. Our technique is known as the Induratec™ process."

Conventional techniques and equipment are used to form a micro-alloy containing both the solid lubricant and the substrate. Buehler adds, "The solid lubricant will literally become an integral part of the substrate. Preparation of the micro-alloy will typically take only a few minutes. The amount of force required is dependent upon the application."

The thickness of the micro-alloy is typically less than two microns. Buehler says, "The thickness of the micro-alloy is dependent upon the hardness of the substrate. Greater surface penetration is achieved with softer surfaces."

The micro-alloy is best applied to surfaces that will be dry sliding against each other. Buehler says, "Our objective was to generate micro-alloys on the asperities extending from most surfaces. These asperities are deformed or ploughed as the surfaces meet, which is the root cause for interfacial friction."

The micro-alloy prevents the asperities in sliding services from deforming and tearing material. They are present in the micro voids and crevasses between the sliding surfaces. Buehler explains, "Upon the application of a load under boundary lubrication conditions, the micro-alloy will form stacked layers of platelets, which is a lamellar structure. These platelets are present on the asperities and prevent the asperities present on each surface from gouging the adjacent surface."

The micro-alloy's ability to reduce friction and wear changes depends upon the difference in hardness between the sliding surfaces. For substrates with greater than a 20% difference in hardness, the micro-alloy will prevent the harder substrate from deforming the softer one.

In the case where the two substrates have less than a 20% difference in hardness, the big concern is adhesion between the surfaces. Buehler says, "Friction caused by adhesion is strongly related to the real area of contact (A_r) between the asperities. The micro-alloy forms a layered lamellar structure that reduces any possible contact between the surfaces, thereby eliminating the possibility of friction developing due to adhesion."

The main difference between the micro-alloy and solid lubricant coatings is the ability of the former to maintain its performance over a greater time period. As the surface erodes over time, the micro-alloy burnishes into the substrate. Buehler adds, "After the surface breaks, the micro-alloy remains very effective because no increase in friction and wear is detected."

Micro-alloys can be formed with the wide spectrum of available solid lubricants. Buehler indicates that the main solid lubricants such as PTFE, molybdenum disulfide and boron nitride have been used on a wide variety of substrates. Ferrous alloys, nonferrous metals (such as aluminum and brass), ceramics, tungsten carbide and polymers (an example is polyetheretherketones or PEEK) have all been evaluated.

The specific solid lubricant micro-alloyed into a surface is dependent upon the application and the substrates. This means that evaluation testing must be done before a specific lubricant formulation is recommended. Such a formulation may involve a mixture of solid lubricants at specific concentrations.

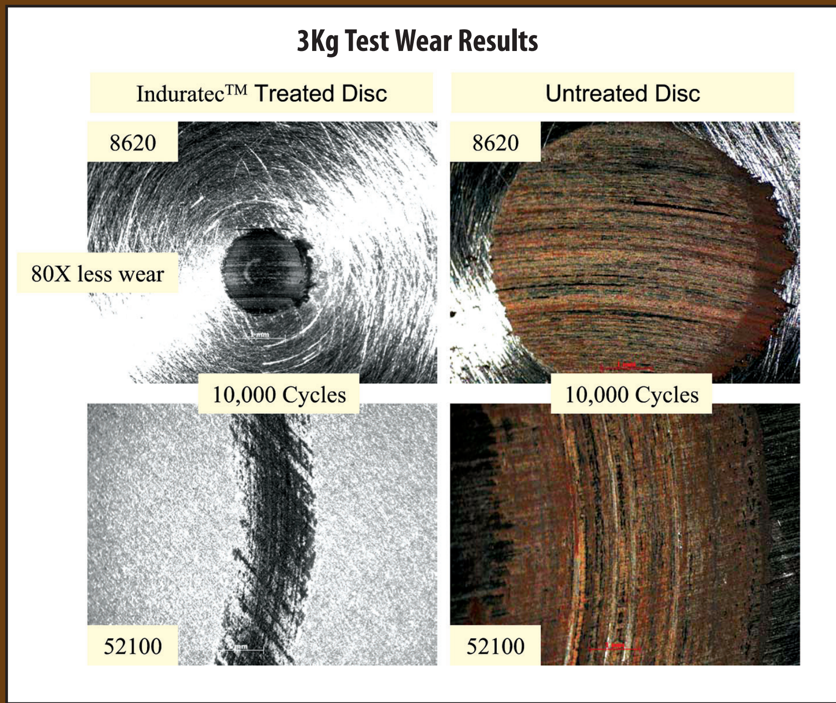
Testing and applications

Much of the work done to assess the effectiveness of micro-alloy formation involves the use of the pin-on-disc tester. An evaluation study was carried out using a disc made from 52100 steel, which is a bearing steel alloy, according to Buehler. The pin used was made from 8620 steel. Both alloys have identical Rockwell Hardness ratings (HRC) of 60.

The test took place for 10,000 cycles under a 3 kg load (240 MPa) and a 2.5 meter/second sliding speed. Dramatic performance improvements were seen after the disc was surface treated with a solid lubricant formulation to form a micro-alloy.

The coefficient of friction for the micro-alloyed disc displayed a 67% reduction as compared to the untreated disc. A similar effect was seen with the coefficient of wear. Analysis of the test results showed that the micro-alloyed disc exhibited a 99% reduction in this parameter as compared to the untreated disc.

Figure 1.



(Photo courtesy of Kinetitec Corp.)

Photographs of the micro-alloyed discs after the test are shown in Figure 1. The untreated disc has a brownish color that reflects surface degradation while the micro-alloyed disc retains the original color and texture of the alloys. The top pictures show the pins while the bottom ones are the discs. Buehler adds, "The surface of the untreated disc is rough and is wearing away. It is definitely undergoing oxidation. In contrast, the micro-alloyed disc is in such good shape that you can see the track of the pin across its surface."

This surface treatment process is being evaluated in a number of applications, including the wheels of railroad cars, forging, bearings, automotive gears, mining and aerospace applications. Buehler says, "We believe this technique is meeting industry needs that have not been previously addressed."

Further information can be found at Kinetitec's Web site, **www.kinetitec.com** or by contacting Buehler at **jbuehler@kinetitec.com**.

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Pins made from 8620 steel and discs made from 52100 steel were evaluated by the pin-on-disc tester to show the effectiveness of micro-alloying a solid lubricant into the surface of the disc by the Induratec™ process. The disc treated with the micro-alloy retains its original color and texture while the untreated disc has a brownish color indicative of surface degradation.

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Developing a 'steel sandwich'

Rising fuel costs have refocused efforts to improve the Corporate Average Fuel Economy (CAFE) of automobiles. The U.S. Department of Transportation announced new standards for light trucks that start at 21.6 miles per gallon (mpg) in 2006 and increase to 24 mpg by 2011. Passenger car standards remain at an average of 27.5 mpg, but the current situation suggests that they will be increased in the near future.

One of the leading procedures used to improve fuel economy has been to lower the weight of the vehicle. The auto industry has a general guideline stating that every 10% reduction in vehicular weight affords a 5% increase in fuel economy.

> **Steel has been the predominant material used in automobiles, but lighter weight alternatives such as aluminum, plastics and magnesium have increased their presence in vehicles during the last 10 years.**

Steel has been the predominant material used in automobiles, but lighter weight alternatives such as aluminum, plastics and magnesium have increased their presence in vehicles during the last 10 years. Aluminum's presence in automobiles has increased to 145 kilograms (kg) or 319 pounds, nearly 10% of the weight of an average North American car (1,525 kg or 3,355 lbs.). Plastics (including thermoplastics, thermosets and composites) also have slowly increased their presence in automobiles to the point where they accounted for 8% of the weight of a North American car in 2004.[1] Magnesium has a much smaller segment of a car (approximately 0.3%), but this metal's presence in the automobile industry has grown dramatically during the past 20 years.

The percentage of steel in an average automobile in North America has dropped approximately 3.5% over the past 10 years (to 41%). But the steel industry has developed new and advanced high-strength products that provide comparable performance to conventional steel but reduce the weight of the vehicle. The new 2006 Mercedes Benz M-Class sports utility vehicle utilizes a high percentage of high-strength steel alloys that contributed in part to a significant weight reduction over the 2005 model.

The steel industry also has been looking to develop metal-hybrid products that combine the strengths of steel and plastics. Success has been achieved through a number of techniques, including inserting metal parts into a mold and then injecting resin and using an adhesive to bond metal to glass fiber reinforced polypropylene.

Steel sandwich

Arcelor has developed a new approach that produces a high strength material that contributes comparable performance to steel but provides valuable weight savings. The product is known as Usilight and is derived from a polymer and zinc-coated, deep-draw quality steel.

Fabrice Pinard, R&D program leader, Multi-Materials Solutions for Arcelor Innovation, says, "Our product is prepared by laminating two zinc-coated steel skins on a polymer core that ranges in thickness from 0.2 to 2.0 millimeters (mm). The key to the process is to ensure that the metal and the polymer are placed in contact with each other. Only a few tons of pressure is required to prepare this steel sandwich." The steel sandwich also can be considered to be a three-layer composite.

The two steel skins each have a thickness of 0.25 mm. Pinard indicated that the steel alloy was used to meet the requirements of customers particularly with regard to painting. The steel sandwich material will withstand a temperature of 200 C for an hour without degradation. This condition is present during the electrodeposition paint process.

Two different polymer cores are available for use between the steel skins. Polymer B is a proprietary resin patented by Arcelor that will hold up to the electrodeposition procedure. In contrast, Polymer A is a cheaper thermoplastic resin that will maintain its physical properties up to 160 C. Pinard says, "No residue formation is seen on the steel sandwich when material made with Polymer B is subjected to electrodeposition."

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The key performance characteristic of the steel sandwich is its combination of high stiffness and low weight. For example, a steel sandwich with a thickness of 1.3 mm and a weight of 4.73 kg/m^2 exhibits the same stiffness as a 1.2 mm thick steel sheet. The steel sandwich has a weight comparable to 0.6 mm thick steel sheet, which is two times thinner.

The steel sandwich also shows a similar benefit when compared to aluminum sheet. Aluminum with a thickness of 1.7 mm achieves the same stiffness as the steel sandwich with a thickness of 1.3 mm.

Pinard adds, "Our objective is to produce a material with an excellent stiffness-to-weight ratio. The steel sandwich has the potential to provide attractive weight savings to the automotive industry."

Figure 2.

(Photo courtesy of Arcelor S.A.)

This hood from an automobile was produced using a steel sandwich known as Usilight.

The steel sandwich exhibited excellent performance in a variety of OEM corrosion tests. Pinard says, "Automotive parts made with the steel sandwich were evaluated by a wide range of European standards of various accelerated cyclic corrosion tests."

Samples were tested after electrodeposition painting, and only slight white rust was found in the highly strained zones of the sandwich steel parts. Pinard says this white rust originates from the electrogalvanized steel skin.

The steel sandwich can be readily machined using conventional techniques. Much of the evaluation work done by Arcelor's customers has been with a stamping die. Pinard says, "We found that cutting can be conducted using standard tooling and widely accepted parameters. The gap between tools needs to be adjusted in order to minimize burrs on the steel skin and prevent crimping of the polymer."

Metal-forming processing also can be carried out with standard tooling. Only minor adjustments were required even in difficult operations such as V-Bending. Different geometric prototype parts were produced with no difficulty. Even in the case of deep drawing, no delamination was observed between the polymer and the steel skins.

Applications

The steel sandwich is being evaluated for use in outer panel automotive applications such as roofs and hoods. Figure 2 shows an automotive part made from this material. Pinard says, "We have already achieved 30% to 40% weight savings as compared to steel on these two applications."

The steel sandwich is being used commercially in trains. Pinard says, "Our technology has undergone extensive performance testing in automobiles. We are close to achieving a commercial commitment from our customers."

Further details on the properties and performance testing of the steel sandwich can be found in a recent paper.[2]

References

[1] Tullo, A. (2006), "Driving Efficiency," *Chemical and Engineering News*, **84**, (24), pp. 12–18.

[2] Dunand, M. and Gacel, J.-N. (2006), "USILIGHT: a cost effective solution to lighten cars," SAE 2006 *World Congress & Exhibition*, **Document Number: 2006-01-1216**.

New adhesive fights bacteria growth in MWFs

Microbial contamination remains a major problem in lubrication, particularly with metalworking fluids. Bacteria literally utilize the components in the fluid as food. The result is that fluid stability declines, making maintenance a more challenging task.

Bacteria can form biomasses that can

plug filters, restrict coolant flow and have a negative influence on corrosion by impeding chip removal. The end-user is faced with having to rely on the introduction of tankside additives such as rust preventatives and antifoams to keep the metalworking fluid operational.

Determination of bacterial content in metalworking fluids is usually done by using a dipslide. A sample of the fluid is taken and evaluated. Unfortunately, this may not be representative of the actual bacteria level because an important proportion of bacteria live attached to surfaces.

Yves Brun, professor and director of the Microbiology Program at Indiana University, says, "Nutrients for bacteria tend to absorb to surfaces. This leads bacteria to grow on those surfaces where their nutrients are found. As part of this process, bacteria then develop multicellular structures known as biofilms."

Effectively treating biofilms with antimicrobial pesticides can be very difficult. If a determination can be made about how the bacteria attach themselves to surfaces, then specific additives can be developed to detach bacteria from surfaces, or the surfaces themselves could be designed to be immune to bacterial infestation.

Caulobacter crescentus

Brun and researchers from Brown University have discovered that a gram negative bacterium known as *Caulobacter* (*C.*) *crescentus* produces an exceptionally strong adhesive that exhibits a sticking power approaching 70 Newtons (N) per square millimeter (mm^2). As a comparison, conventional "super glue" can withstand a shear force of 18 to 28 Newtons/mm^2. Brun comments, "A quarter-size patch of the adhesive produced by *C. crescentus* could conceivably suspend a 5-ton elephant."

C. crescentus is a common bacterium that is found in all types of aquatic environments. Brun says, "This bacterium species is a great model system to use to study the properties of bacteria. It is easy to grow, and the cells in a culture can be easily synchronized so that they are all growing at the same stage of their life cycle." Of additional importance is that *C. crescentus* is also know to be one of the first bacterium species to attach to surfaces in an aqueous environment and generate the formation of biomass.

The structure of the bacterium provides a strong indication of where the adhesive is produced and how it is used to keep the organism attached to the surface. *C. crescentus* develops foot-like structures known as holdfasts at the end of thin stalks. These holdfasts directly attach the bacterium to a surface. A photograph showing this form of *C. crescentus* is shown in Figure 3.

Brun explains, "The picture shows two cells in the process of dividing as noted by the pinching in the middle. The two lower organisms are known as stalked cells that contain a holdfast at the tip of the stalk. Once cell division takes place, the two higher organisms produced will be known as swarmer cells. This

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Figure 3.

(Photo courtesy of professor Yves Brun, Indiana University)

Two cells of the gram negative bacterium, *C. crescentus* are shown in the process of dividing as noted by the pinching in the middle. The bottom two cells have developed foot-like structures known as holdfasts at the end of thin stalks. An exceptionally, strong adhesive is produced in the holdfast to enable the cells to remain attached to surfaces.

'Nutrients for bacteria tend to absorb to surfaces. This leads bacteria to grow on those surfaces where their nutrients are found. As part of this process, bacteria then develop multicellular structures known as biofilms.'

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cell type contains flagellum (tails) that enables them to move to another location and then grow their own holdfast and stalk." This type of process can readily lead to the growth of biofilm.

Polysaccharide-based adhesive

The researchers developed a procedure for measuring the adhesive force that holds *C. crescentus* to a surface. Individual bacteria are attached to a thin pipette and then subjected to suction from a second pipette. The cell is pulled away in a perpendicular direction from the thin pipette. Brun says, "We were able to easily isolate swarmer cells and allow them to attach on the flexible pipette so that they would grow holdfasts and stalks and attach tightly to the surface."

'The stalk is the most fragile part of the bacterium and as a result breaks first under the pressure exerted. This means that the actual force needed to remove the holdfast from a surface is higher.'

The average force needed to pry *C. crescentus* from the surface is between 0.59 and 0.62 micronewtons. Most other species of bacteria cling to surfaces, but do not exhibit the adhesive properties displayed by *C. crescentus*. Brun adds, "The force needed to pull off the vast majority of bacteria species is up to 10's of nanonewtons, which is much smaller than is required for *C. crescentus*."

Brun says that *C. crescentus* developed this type of adhesion as a means to adapt to its aquatic environment. Evidently, this bacterium is exposed at the air-water interface to waves with forces in the micronewton range.

Atomic force microscopy (AFM) imaging was done to determine the average diameter of a stalk. Based on this information, the stress that the stalk could withstand was estimated to be 68 N/mm^2. Brun says, "The stalk is the most fragile part of the bacterium and as a result breaks first under the pressure exerted. This means that the actual force needed to remove the holdfast from a surface is higher."

The exact composition of the adhesive contained in the holdfast has not been determined. Polysaccharides based on N-acetylglucosamine are a key component in the holdfast. These polysaccharides are biodegradable and can literally be broken down by the enzyme lysozyme, which is present in human body mucosal secretions such as saliva and tears.

Brun says, "Treating the holdfast with lysozyme leads to a reduction in the adhesion ability of the bacterium. The adhesive force exerted by the holdfast can decline by 100-fold." Future work will be done using AFM to probe the very small surface area in contact with the holdfast as a means to more accurately measure the adhesive force.

Brun believes that the adhesive produced by *C. crescentus* has potential commercial applications because it will function on wet surfaces. For example, the material could be used to coat surfaces for medical and engineering uses as a surgical adhesive. Another plausible application for this material is ship repair at sea.

Brun would like to carry out future studies to better understand the physical properties of the adhesive and its chemical composition. Further information about the research done to measure the adhesive force of *C. crescentus* can be found in a recent article.[1]

The prospect that a polysaccharide-based material is the reason that bacteria can attach themselves to surfaces and form biofilms may also lead to new approaches for controlling their growth. Future antimicrobial pesticides used to treat metalworking fluids could be based on natural substances that degrade these polysaccharide-based adhesives. **<<**

Reference

[1] Tsang, P., Li, G., Brun, Y., Freund, L. and Tang, J. (2006), "Adhesion of single bacterial cells in the micronewton range," *Proc. Natl. Acad. Sci. USA*, **103** (15), pp. 5764–5768.

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