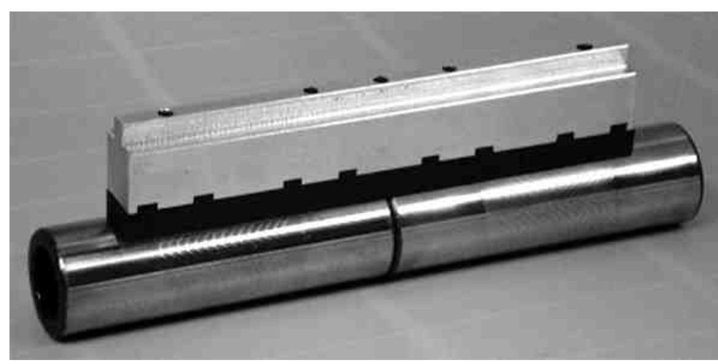
FriCSo's Innovative, Environmentally-Friendly Approach to Friction and Wear with Nanolayer-Based Technology



Typical external diameter lapping fixture with attached FriCSo polymer insert (the darker element in contact with piston pin). Note the grooved surface texture on left half of the piston pin.

Like death and taxes, friction and wear are unavoidable, and countless years of effort have been expended to reduce their deleterious effects. With increasing environmental concerns and regulation on a global basis, several tried-and-true staples in dealing with friction and wear, such as hexavalent-based hard chromium plating, have been or will be largely eliminated from commerce. In turn, a quest for viable substitutes has been ongoing.

A most novel approach to friction-reducing surface treatment has been developed by FriCSo, with headquarters located in Farmington Hills, Michigan and strategically situated in the center of the North American automotive industry. The innovative treatment combines nanolayer-based technology with existing in-line mass-production equipment and off-the-shelf abrasive pastes, and offers an environmentally-friendly technology system that significantly reduces friction and retains oil between moving parts.

The company name, FriCSo, with its mixed-case spelling, stands for "**Fri**ction **C**ontrol **So**lutions." This relatively young company was founded in 2003 by Dr. Boris Shamshidov and Dr. Alexander Ignatovsky, two scientists specializing in tribology, the science of friction, lubrication and wear. Prior to founding the company, they worked at the tribological laboratory at Technion - Israel Institute of Technology. Beside the company headquarters in Farmington Hills, the FriCSo R&D and international marketing centers are located in the Tirat Hacarmel Industrial Zone, in Israel. FriCSo currently employs about 20 people.

Setup for internal honing operation using FriCSo polymer inserts.

The essence of FriCSo's technology is a two-step process, dubbed "SET," for Surface Engineering Technology. Given that there are some variations, the basic SET treatment consists of:

- Polymer lapping - using a patented, consumable polymeric tool to apply a durable organic nanolayer to the surface to enhance its oil retention properties.
- Surface texturing (grooving or laser dimples) - to impart a texture within the surface to act as a lubricant "reservoir," and as funnels for wear particles.

Applications are numerous, including cylinder liners, camshafts, rocker shafts valves and piston pins in internal combustion engines; shock absorber strut rods, steering columns and CV (constant velocity) joints for automobiles; pistons and swash plates in hydraulic motors and pumps and rotating shafts / bearings in a variety of machinery. What is most attractive in all of this is the ability to apply SET using existing superfinishing equipment.

FriCSo's technology supports its users in achieving their objectives in the following fields:

- Complying with environmental regulations (reducing fuel consumption, reducing emission levels, replacing coatings made of hazardous materials)
- Increasing performance (extending the service life of parts, reducing fuel consumption, increasing the output of engines).
- Reducing costs compared to coatings, bushings and friction pair designs

FriCSo was selected as the recipient of the 2006 Frost and Sullivan Technology Innovation Award for the development of their innovative Surface Engineering Technology. As set out by Frost and Sullivan, the award is "bestowed upon a company (or individual) that has carried out new research, which has resulted in innovation(s) that have or are expected to bring significant contributions to the industry in terms of adoption, change and competitive posture. This award recognizes the quality and depth of a company's research and development program as well as the vision and risk-taking that enabled it to undertake such an endeavor."

Polymer lapping

The centerpiece of FriCSo's environmentally-friendly process is the polymer lapping. The tooling involved is identical to what is typically used in any superfinishing operation and with conventional off-the-shelf abrasive pastes. As shown in the accompanying figures, both external diameter lapping and internal honing can be readily accomplished with conventional equipment. The difference is that the superfinishing insert consists of the innovative organic polymer material used in the lapping/honing process.

The formulation of the polymer is the result of several years of extensive research. The unique property of the patented polymer was to deposit an organic polymer layer, of nanoscale thickness, on the basis metal substrate from the polymer material. Formed from polymeric particles detached during the lapping process, this layer forms a strong chemical metal-organic bond to the metal. This organic nanolayer increases the oil adhesion to the treated metallic surface, resulting in friction reduction under severe operating conditions.

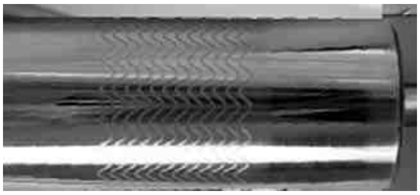
Besides the unique abilities of forming the organic nanolayer, the polymeric lapping material must - simply put - also do the lapping. Accordingly, the polymer in the lapping tool had to satisfy the necessary mechanical properties of hardness, impact resistance and wear resistance. Further, the material had to satisfy those operational parameters germane to the lapping process. This includes such requirements as the ability to remove material effectively, the ability to reduce surface roughness to the desired level and the ability to maintain integrity under the thermal conditions of lapping (*i.e.*, heat resistance). These are requirements of any lapping material, but FriCSo's goals were to exceed significantly the performance of conventional superfinishing.

Since its discovery, the polymer formulation has been modified to optimize the three performance categories: the chemical properties to form the nanolayer, as well as the mechanical and operational properties to act as a lapping tool.

Grooving

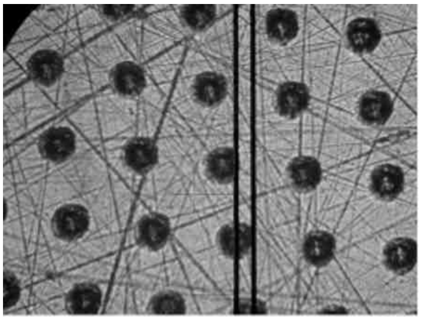
The first step of FriCSo's two-step process is texturing. This process is intended to impart a surface texture on the surface of the workpiece. The texture is a pattern of shallow grooves or laser-generated dimples on the surface. The geometry provides additional lubricant available when conditions of boundary lubrication, where a single molecular monolayer of lubricant lies between the interacting surfaces, or complete lubricant starvation exist. A typical grooving pattern can be seen on the surface of the piston pin shown in the figure.

It is important to note that, in the early development of the process, grooving alone had been investigated as a possible one-step process but there were shortcomings with this approach. It was only with the advent of polymer lapping with the innovative polymeric material developed

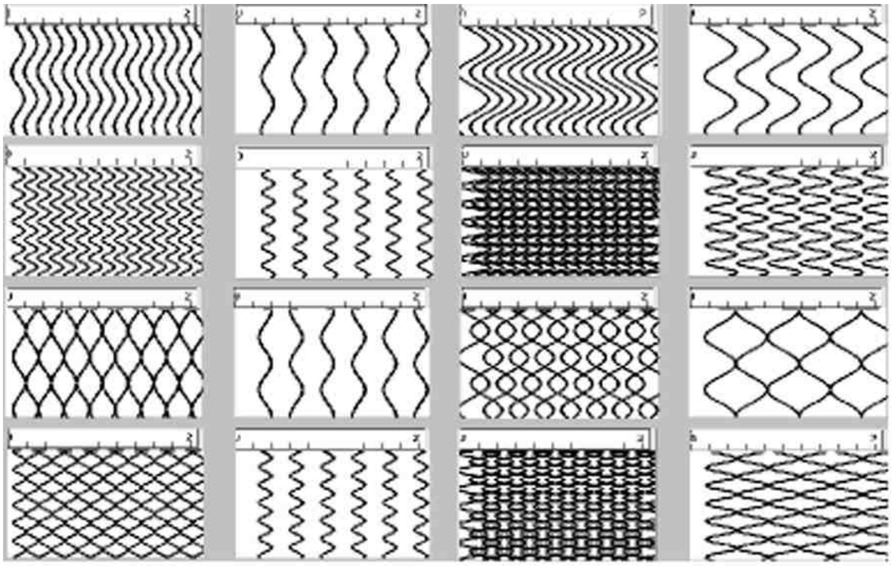


Pattern imparted by the grooving process on the surface of an automotive piston pin.

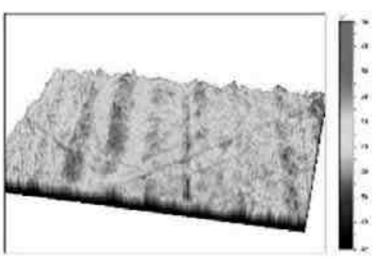
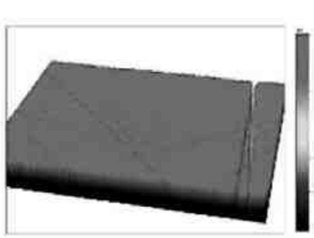
Schematic cross-section of the grooving process, showing the ridges formed by plastic deformation.



Example of laser dimpled steel surface.



Examples of surface patterns that can be created with grooving.

Description	Height histogram	Average roughness (Ra)	maximum height of profile (Rt)
Commercial washer, ground as in the production process		0.42 µm	3.3 µm
Commercial washer, superfinished as in production process		0.07 µm	0.25 µm
Commercial washer, after FriCSo polymer lapping		0.02 µm	0.13 µm

Comparison of surface topography: (Upper) as originally ground; (Center) Conventional superfinishing; (Lower) FriCSo polymer lapping.

by FriCSo that the SET process, using grooving became viable.

The pattern is applied by a mechanical element, programmed to form the designed pattern. As seen in the schematic cross-section, a groove is formed in the process. However, no metal is removed at this point and a pair of ridges flanks either side of the groove. The presence of these ridges was the heart of the problem associated with the inability of grooving to be effective on its own.

It is clear that the ridges must be removed, and subsequent superfinishing, or lapping (honing in the case of inside diameters) is used to remove them. However, with conventional lapping or honing operations, sharp groove edges are still left behind. Of course, these are not desirable as they will do damage to the opposing surface in actual application. This is where FriCSo's unique polymer lapping comes into play.

Before leaving the subject of grooving, it is important to discuss the grooved pattern itself. The pattern shown on the piston pin earlier in this article is specifically designed for that particular part. As shown here, there are a variety of patterns that can be obtained by a programmed grooving procedure. FriCSo engineers have extensive experience in matching the pattern to a specific part design for optimum performance.

Laser dimpling

It is worthy of note that FriCSo has another means of surface texturing, using lasers. This technique involves forming a regular dot pattern of dimples in the steel surface. The dimples range in size from 30 to 120 μm in diameter and one to 30 μm deep, depending on the application. The thinking behind this concept is that the presence of dimples adds hydrodynamic pressure during use, thereby reducing friction. The use of laser energy to create the dimples results in roughness and sharp edges around the dimple perimeters, which must be removed by some form of superfinishing or with polymer lapping.

FriCSo reports that laser dimpling has shown significant performance benefits over superfinishing or polymer lapping alone in specific applications. One application where laser dimpling has clearly shown superior results is in mechanical seals for hydraulic engines.

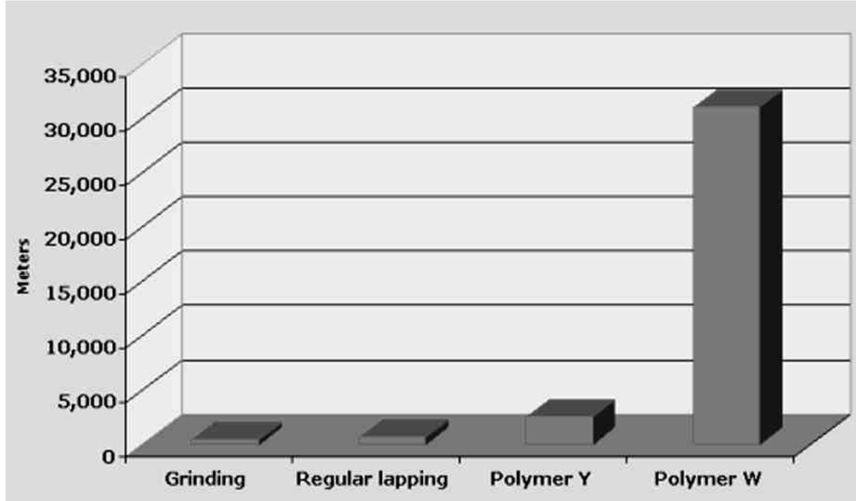
Materials testing

Properties

The properties of SET surfaces have been found to possess properties that exceed most conventional superfinished workpiece surfaces. Exceptional values of surface topography and hardness have been measured.

The degree of flatness achieved is dramatically illustrated in results of a profilometry study shown in the figure at the bottom of page 12. The upper trace is the starting point, after the grinding step. The average roughness, R_A, is 4.2 μm. Conventional superfinishing, in the middle trace, yields a respectable R_A value of 0.07 μm. Polymer lapping, in the lower trace, reduces this value by two-thirds, reaching an R_A of 0.2 μm. The uniform shading of the trace profile shows the result rather markedly. The removal of any protrusions remaining from grooving by polymer lapping is also borne out by these results.

Significant hardening of the substrate surface is also achieved during the polymer lapping process. In a third-party study, the surfaces of steel substrates with a bulk hardness of 500 VHN were subjected to conventional superfinishing and polymer lapping and compared. Both processes generate mechanical and thermal energy sufficient to work harden the surface material. In the case of conventional superfinishing, a hardness profile through the cross-section of the specimen showed an increase from 500 VHN at a depth of 5.0 μm to 650 VHN at a depth of 1.0 μm below the surface. For the polymer lapped specimen, the hardness at the 1.0 μm depth reached 1,100 VHN, a significant difference. FriCSo engineers relate the results to rotation of the abrasive particles within the polymer which ultimately interact with the surface more intensively and thereby cause greater work hardening.



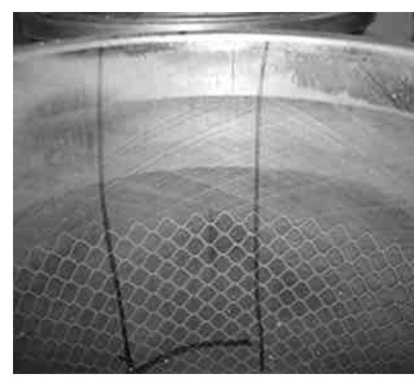
Results of Block-on-Ring Oil Retention Tests

Performance

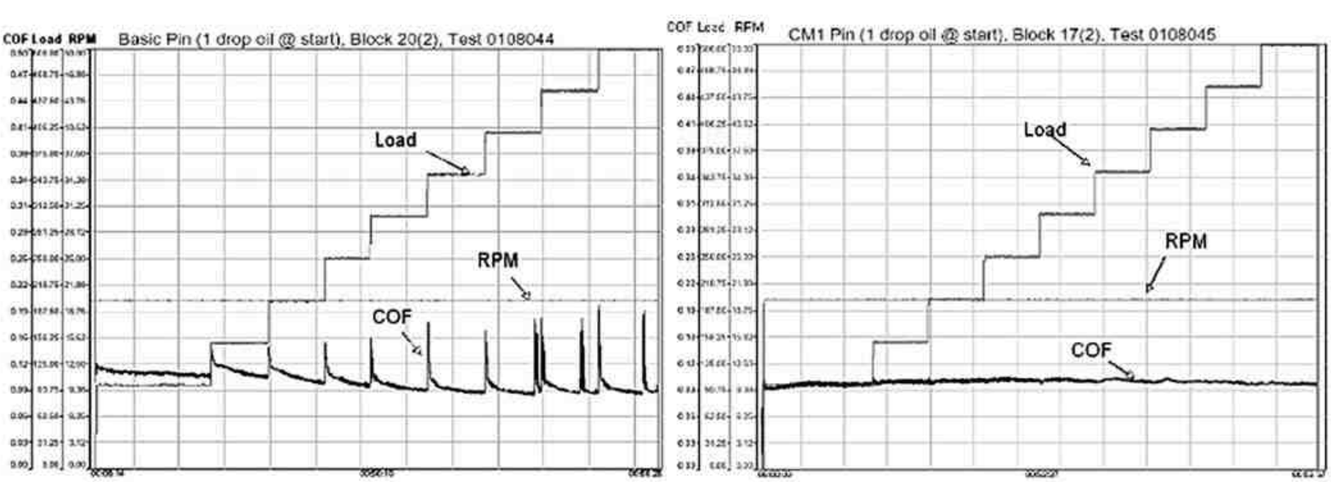
Beyond the measurable static properties, the ultimate proof of the concept lies in the performance of the polymer lapping technology. In particular, performance under marginal boundary lubrication conditions is critical to success.

Much has been discussed about the oil retention capabilities of the polymer nanolayer. Oil retention tests were run under boundary lubrication conditions with a block-on-ring test using hardened steel pairs with various finishes. A single drop of oil was used at a sliding velocity of 2.13 ft/sec (0.65 m/sec) and a normal load of 90 lbf (400 N). The tests were run to the point of seizure. The bar graph shows the results.

Before superfinishing, seizure of the original commercially-ground surface occurred after 656 ft (200 m) of sliding travel. With conventional lapping, the tests specimens endured for approximately



Grooving pattern on inside of cylinder wall.



Comparison of coefficients of friction: (Left) Conventional superfinishing; (Right) Polymer lapping.

twice the distance. Polymer lapping using polymer Y, the first generation of FriCSo's polymer lapping material, resulted in a significant improvement, running out to about 6,500 ft (2,000 m). The second generation polymer W however, exhibited enhancement in performance by more than an order of magnitude over the first generation polymer Y. The test was stopped at 100,000 ft (30,000 m), without showing seizure. Visual examination of the Polymer W test specimen showed no sign of wear or abrasion, with only surface oxidation visible at the line of contact.

Another third party block-on-ring test compared the coefficient of friction of SET (grooving followed by polymer lapping with commercial superfinishing. This time a hardened steel block was used in conjunction with a commercial piston pin. The load was increased step-wise from 100 lb (445 N) to 500 lb (2,220 N) and the sliding velocity was fixed at 20 RPM.

With the conventional superfinish, each stepwise increase in load resulted in a significant increase in friction coefficient, seen as a vertical spike in the graph in the left side of the figure. On the other hand, the coefficient of friction remained steady with each increase in load when the polymer lapped finish was tested.

Applications

As noted earlier, FriCSo had located their American headquarters in southeastern Michigan to be close to the center of the North American automotive industry. They recognized that many automotive applications could benefit from the use of the FriCSo polymer lapping technology. The enhancement of the friction and wear properties noted here, could lead to direct benefits in fuel economy. Studies show that the SET technology is more than a laboratory curiosity.

Recently, extensive testing was performed on a four-cylinder diesel engine in the Internal Combustion Laboratory of Techion - Israel Institute of Technology, and FriCSo. The engine was run with parts receiving no surface treatment as a base line. Several working surfaces in the engine (*i.e.*, the primary friction parts) were SET treated by FriCSo, including:

- Inner cylinder liner surface
- Piston pins
- Rocker shaft
- Valve stem (polymer lapping only)
- Valve tappet (polymer lapping only)

Different grooving patterns were employed on certain surfaces where experience showed that performance could be enhanced. For example, the pattern used on the inner surface of the cylinder liner differed from that on the piston pin shown at the beginning of this article.

The results with the SET treatment showed improvements on several fronts. Depending on the engine speed and load, fuel consumption was reduced by from 0.4% to 4.0%. Oil consumption was reduced significantly, by 48%, while diesel particulate emissions were reduced by 43 to 46%. These two findings are very noteworthy. Further analysis indicated that the overall mechanical efficiency of the engine was increased by about 2%. These are significant numbers when one considers that the only thing done to the engine was to modify the primary friction surfaces.

The surface engineering field has taken many strides over the last several years, driven by changing priorities of health, safety and environmental concerns, as well as energy needs. Innovations from young companies such as FriCSo, Ltd. show promise in addressing these shifting priorities. As the SET technology shows, breakthroughs can change thinking rather quickly. *P&SF*

Further reading

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