# C. Laser Texturing of Materials

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## Objectives

- Assess and optimize the tribological performance of laser-textured (or -dimpled) surfaces under sliding and/or rotating contact conditions.
- Determine durability and operational limits of dimpled surfaces with respect to dimple size, depth, and density.
- Elucidate fundamental tribological mechanisms involved with laser-dimpled surfaces.
- Design and produce novel hard coatings over dimpled surfaces and explore any beneficial synergistic effects that such coatings may have on friction and wear.

## Approach

- Control and optimize parameters used in the laser-texturing process in order to obtain the most desired dimple size, depth, and density on a series of steel and SiC samples.
- Control and eliminate bulges and other surface irregularities caused by the dimpling process on and around the rims of dimpled spots. Use a post-process grinding/polishing procedure to remove such irregularities.
- Thoroughly examine and characterize dimpled surfaces by optical and electron microscopes and by a 3-dimensional (3D) surface profilometer. Determine dimple size, depth, and density. Take several representative images.
- Develop a test matrix, specify test conditions, and perform well-controlled tests with unidirectional and reciprocating wear test machines.
- In collaboration with Izhak Etsion (who supplies the dimpled surfaces), analyze test results and make judgments on the performance of the dimpled surfaces.
- Specify and apply hard coatings over laser-dimpled surfaces. Characterize and perform standard tests to assess performance improvements.
- Promote/present findings at appropriate forums and generate more industrial interest.

## Accomplishments

- Demonstrated lower friction and wear under mixed lubrication regimes using a unidirectional test rig.
- Demonstrated an increase of up to 90% in resistance to scuffing on laser-dimpled surfaces using a reciprocating test rig.
  - Modified a reciprocating test rig that can now simulate the motion between a piston ring (or skirt) and cylinder liner of an internal combustion engine.
  - Initiated series of tests on cut segments of piston rings and cylinder liners using the modified reciprocating test rig.
  - Successfully produced and optimized shallow (5 to 6 micrometers deep) dimples on mechanical face seals and demonstrated superior performance, lower torque (more than 40% lower), and minimal wear for dimpled surfaces (especially under lower face pressures).
  - Performed series of tests on coated and laser-dimpled surfaces and determined operating conditions under which maximum beneficial synergistic effects can be realized.

## Future Direction

- Concentrate on laser-dimpled piston rings and cylinder liners; perform friction and wear tests under conditions that represent actual engine applications.
- Analyze friction and wear data; characterize worn surfaces; determine levels of improvements provided by dimpling process.
- Assess friction reduction and energy-saving benefits of laser-dimpled rings and liners.
- Perform more studies on laser-dimpled seal faces.
- Determine effects of depth, size, and density of microdimpling on scuffing performance of surfaces coated with hard and soft films. Specifically, evaluate the effects of an MoN coating on friction and wear of laser surface texturing-treated surfaces.
- Determine effects of oil viscosity and/or ambient temperature on friction and wear behavior of dimpled surfaces.
- Determine microstructural, chemical, and mechanical characteristics of heat-affected zones at or near the dimpled areas and determine their impact on friction and wear.

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## Introduction

Argonne National Laboratory has entered into an exploratory research program with Technion University to evaluate the potential usefulness of a laser surface texturing or dimpling technology for engine and drivetrain applications. This technology produces shallow dimples (typically 4–10 μm deep) 70 to 100 μm in diameter on metallic or ceramic surfaces (see Figure 1). When such surfaces are used under mixed or hydrodynamic regimes of lubricated contacts, substantial reductions in friction and wear are observed. A major goal of this project is to produce and further optimize such dimples on sliding and rotating contact surfaces of critical engine parts and components to reduce friction and wear. Furthermore, synergistic effects of hard coatings on friction and wear of laser-dimpled surfaces are being explored.

Laser texturing may be an ideal technology for applications in mechanical face seals, as well as in various engine and drivetrain components such as piston rings and cylinder liners and wrist pins. In such applications, shallow dimples can serve as reservoirs for fluid media (i.e., oil and/or water) and thus increase the hydrodynamic lubrication efficiency of these surfaces. Furthermore, dimples can effectively trap wear debris or third-body particles generating at sliding interfaces as a result of contact sliding and thus reduce wear. Overall, when such optimized dimples are produced on various engine and drivetrain components, much improved fuel economy due to reduced friction or torque can be expected, and reduced wear translates into longer durability and hence reliability.

Accordingly, during this work period, we have prepared large numbers of SiC face seals, AISI H-13 steel flats, and cut segments of piston rings and cylinder liners for laser texturing at SurTech. Dimpled samples were returned to Argonne for surface characterization and tribological testing. Some of the dimpled seals were subjected to rigorous wear testing, while others were used in a seal tester to measure torque. Some of the dimpled steel substrates were further coated with a superhard nanocomposite MoN film in order to further improve their friction and wear performance, especially under harsh sliding conditions that can lead to scuffing and hence major wear losses.

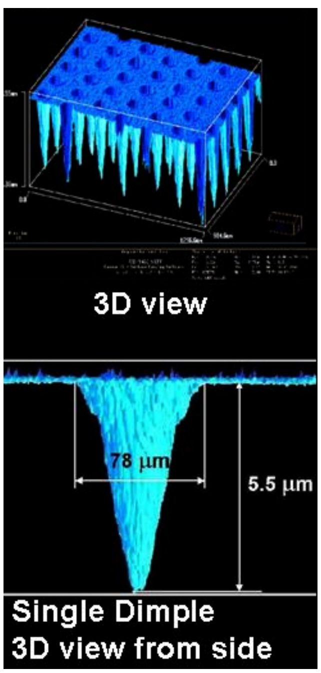


**Figure 1**. 3D images of dimpled surface and individual dimple.

## Results

### Effects of Point and Conformal Contacts on Friction and Wear

Figure 2 shows surface conditions of three different samples (polished, ground, and dimpled) that were used in a series of sliding tests in a unidirec

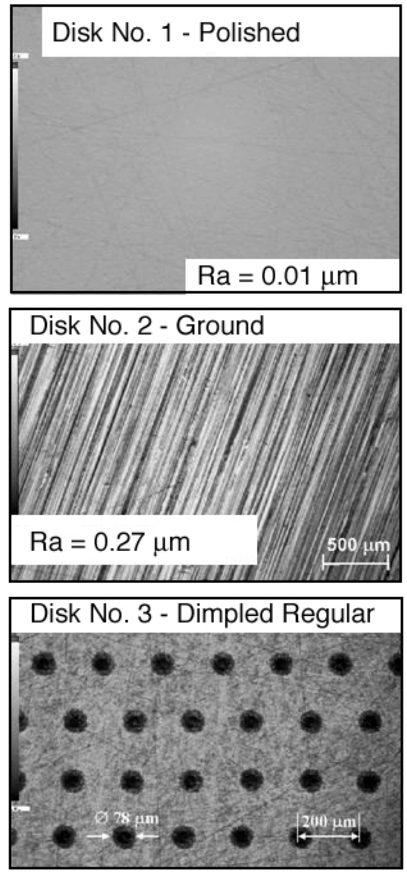


**Figure 2.** Surface conditions of H13 steel flats used in sliding experiments with point and conformal contacts.

tionally sliding wear test machine. These samples were rubbed against both spherical balls (≈10 mm in diameter) and flat-ended pins under lubricated sliding conditions. Figure 3 shows the variation of friction coefficients of balls and flat pins against polished, ground, and dimpled H13 steel surfaces as a function of increasing sliding time and speed. As is clear, under both contact configurations, a dimpled surface (Disk #3) provided the lowest friction (especially against the flat-ended pin). However, the friction coefficient of dimpled surfaces was much higher than when they were rubbed against the spherical ball. This may have been due to the relatively high contact pressures that can be generated under such point contact situations. Formation of a complete or continuous hydrodynamic film (which is key for separation of the sliding surfaces) also becomes very difficult under high-pressure point contact. The higher overall roughness of the dimpled surfaces may also have an adverse effect on friction behavior. Specifically, relatively rough sur-

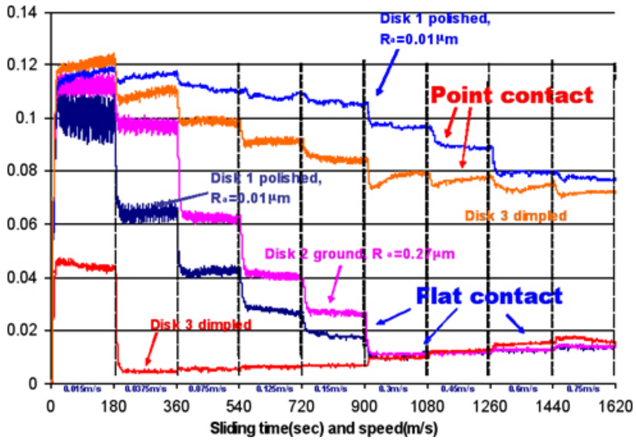


**Figure 3.** Frictional performance of steel balls (point contact) and flat-ended pins (conformal contact) against polished, ground, and laser-dimpled H13 steel surfaces.

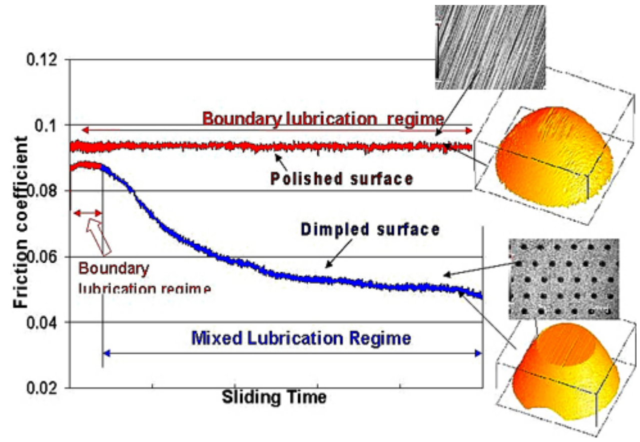


**Figure 4.** Friction and wear performance of M50 balls during sliding against polished and laser-dimpled H13 steel flats.

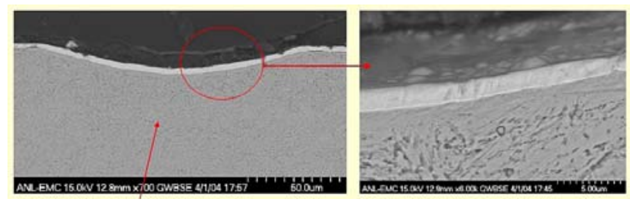

**Figure 5.** Hard coating applied over a dimple, and magnified details of segment showing coating and steel substrate.

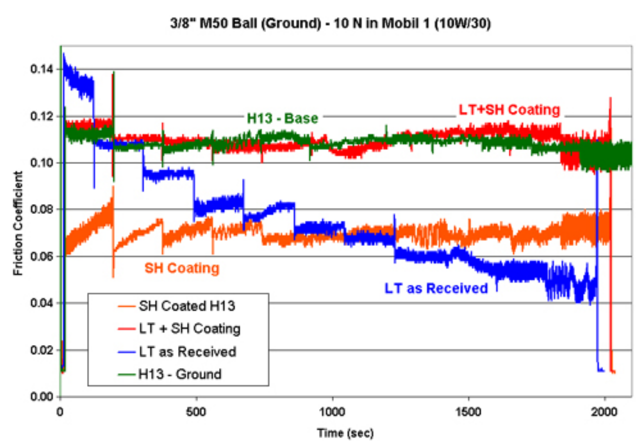


**Figure 6.** Friction behavior of as-received, laser-dimpled, and laser-dimpled + superhard MoN-coated surfaces under boundary-lubricated sliding conditions.

faces of dimpled samples may adversely affect the formation of a continuous hydrodynamic film, leading to increased friction between the sliding surfaces.

Figure 4 summarizes the friction and wear behavior of a polished and laser-dimpled H13 steel surface under boundary-lubricated sliding conditions during a constant-speed sliding test over a long duration. Highly polished surfaces of ball and flat samples become very rough as a result of wear under the severe contact pressures of point contact sliding condition, and the friction remains high (i.e., 0.09). For the laser-dimpled surface, friction is high initially but decreases steadily during successive sliding passes and eventually reaches a value of 0.05. The contact surfaces of steel balls wear out and become highly polished. It is quite possible that substantial reduction in friction during sliding may have resulted from ball wear and hence an increasingly conformal contact between ball and dimpled flat.

## Integrating Dimpling with Hard Coatings

Some of the laser-dimpled H13 steel flats were further given a superhard coating. Friction and wear tests were performed in a reciprocating test machine under both point and conformal contact conditions. Figure 5 shows the details of a dimple and the hard coating produced over it.

Figure 6 compares the friction performance of as-received base steel, laser-dimpled steel, and superhard-coated + laser-dimpled steel surfaces under boundary-lubricated sliding conditions.

Based on the results of Figure 6, it is clear that laser-dimpled and superhard-coated steel surfaces give fairly low friction coefficients, while the base steel and laser-dimpled + superhard-coated surfaces provide the same levels of friction. Surface studies after the tests indicated that despite their relatively higher friction, laser-dimpled + superhard-coated surfaces suffered the least wear regardless of contact loads (see Figure 7).

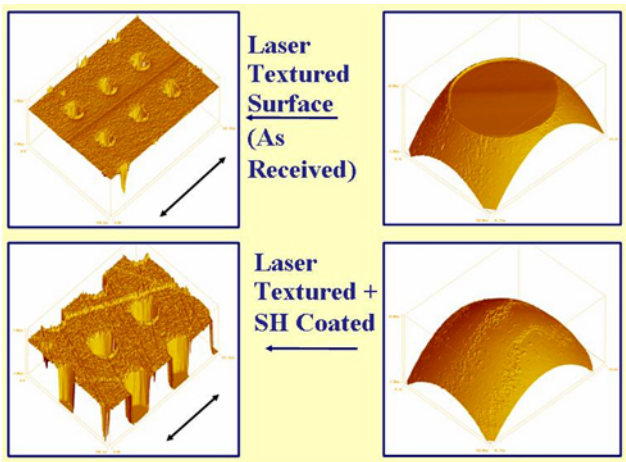


**Figure 7.** Wear performance of sliding ball surfaces against laser-dimpled and laser-dimpled + superhard MoN-coated (SH) flat steel samples

## Laser-Dimpled SiC seals

During this work period, we have performed numerous torque measurements on dimpled and as-received (undimpled) SiC seal faces using an instrumented seal test machine. Figure 8 summarizes the results of these measurements. As is clear, frictional torque on undimpled seal faces increases almost linearly with increasing face pressure. The dimpled SiC seal faces show essentially the same trend, but the magnitude of frictional torque is at least 50% lower across the pressure range evaluated in these studies. Clearly, the dimpled seal faces provide much lower torque and hence may be very beneficial for demanding mechanical face-seal applications, including water pump seals of heavy-duty diesel engines.

## Reciprocating Tests with Dimpled Piston Rings and Liner

During this period, we have cut and prepared a number of segments of actual piston rings and cylinder liners for friction and wear studies using a reciprocating test machine. Figure 9 shows the layout of this machine, while Figure 10 shows a 3D image of a cut segment of a ring with dimples produced on

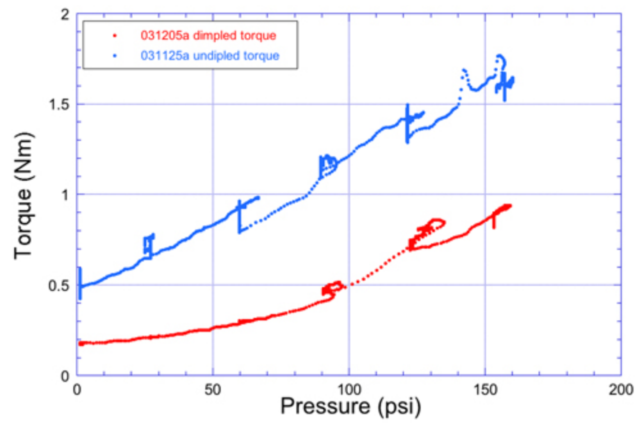


**Figure 8.** Summary of torque measurements on dimpled and undimpled SiC seal faces.

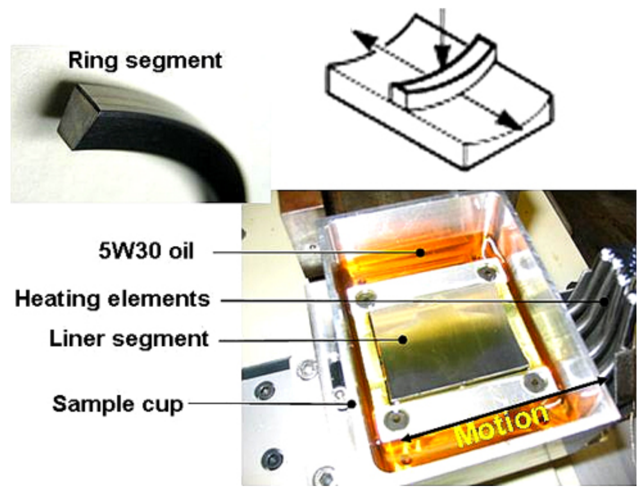


**Figure 9.** General layout of cut segments of dimpled piston ring and cylinder liner placed in its holder in a reciprocating test machine.

its crown. Work is in progress, and the results of initial studies look very promising.

## Conclusions

During FY 2004, we have made great progress in the optimization, testing, and diverse utilization of a laser-texturing process. When used on coated or uncoated surfaces of steel or ceramic (SiC) test pairs, the process results in substantial reductions in friction and/or torque. When combined with a superhard coating technology, it can lead to superior wear performance. Used on SiC seal faces, it can reduce frictional torque by more than 50%. During this fiscal year, we have also produced well-controlled dimples on the surfaces of both piston

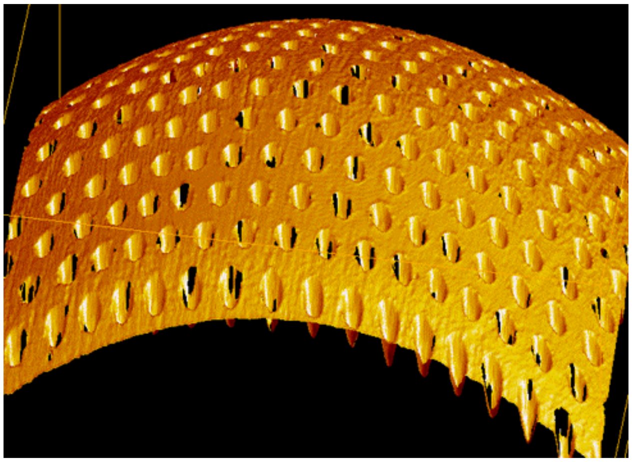

**Figure 10.** 3D image of laser-dimpled ring sample to be tested in reciprocating test machine.

rings and liners. A series of tests is currently under way and covers a wide range of test conditions.

## Patents

An invention disclose has been filed with Argonne's Intellectual Property Department. This invention covers structural and chemical modulation of tribological surfaces by combined use of laser texturing and low-friction superhard coatings.

## Publications

A. Kovalchenko, O. Ajayi, A. Erdemir, G. Fenske, I. Etsion, "The Effect of Laser Texturing on Steel Surfaces and Speed-Load Parameters on the Transition of Lubrication Regime from Boundary to Hydrodynamic," *Tribology Transactions*, **47**(2), 299–307 (2004).

A. Erdemir, "Review of Engineered Tribological Interfaces for Improved Boundary Lubrication," *Tribology International*, in press.

A. Erdemir, "Smart Surface Engineering for Improved Boundary Lubrication," pp. 13–20 in *Proceedings of 14$^{th}$ International Colloquium on Tribology and Lubrication Engineering*, Stuttgart, Germany, January 13–15, 2004 (invited keynote paper).

C. Donnet and A. Erdemir, "Historical Developments and New Trends in Tribological and Solid Lubricant Coatings," *Surface and Coatings Technology*, **180–81**, 76–84 (2004).

K. Kazmanli, O. L. Eryilmaz, O. Ajayi, A. Erdemir, I. Etsion, "Effects of Soft and Hard Coatings on Tribological Behavior of Laser Textured Surfaces," submitted for presentation at the 60th Annual Meeting of the Society of Tribologists and Lubrication Engineers, May 15–19, 2005, Las Vegas.

A. Erdemir, "Engineered Tribological Interfaces for Improved Friction, Wear and Lubrication in Engines," invited panel presentation at Engine and Drivetrain Session of 59$^{th}$ Annual Meeting of the Society of Tribologists and Lubrication Engineers, Toronto, Canada, May 17–20, 2004.

A. Kovalchenko, O. Ajayi, A. Erdemir, G. Fenske, I. Etsion, "The Effect of Laser Surface Texturing on Transitions in Lubrication Regimes during Unidirectional Sliding Contacts," *Tribology International*, in press.