IMPROVING TRIBILOGICAL PERFORMANCE OF MECHANICAL SEALS BY LASER SURFACE TEXTURING

by

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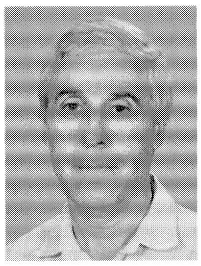

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Dr. Etsion started Surface Technologies Ltd. (Surtech) in 1996 at the Technion Entrepreneurial Incubator Company. Surtech performs research and development in the field of tribology and surface engineering and, more specifically, in laser surface texturing (LST) to enhance tribological performance of mechanical components.

Dr. Etsion received his B.Sc. (1964), M.Sc. (1971), and D.Sc. (1974) degrees (Aeronautical Engineering) from the Technion Israel Institute of Technology.

ABSTRACT

Significant improvement in load capacity, wear resistance, friction coefficient, etc., of mechanical seals can be obtained by forming regular microsurface structure in the form of micropores on their surfaces. A feasibility study was performed experimentally using laser surface texturing (LST) technique to produce the micropores. Each micropore can serve either as a microhydrodynamic bearing in cases of full or mixed lubrication or as a microreservoir for lubricant in cases of starved lubrication conditions. Laboratory tests were performed, mainly with water, to investigate the potential of LST in mechanical seals. In all the tests, friction and face temperature were reduced, wear resistance was increased, and life was prolonged.

INTRODUCTION

A proper hydrodynamic or mixed lubrication is a necessary condition for safe operation of noncontacting or contacting mechanical seals. An important feature of the lubricating film is to provide enough stiffness to prevent or ease the contact between the seal mating surfaces in relative sliding, and thus to reduce friction and wear and to eliminate possible failure due to seizure.

Significant improvement in load capacity, wear resistance, friction coefficient, etc., of mechanical seals can be obtained by forming regular microsurface structure in the form of micropores (Figure 1) on their surfaces. These micropores can serve either as microbearings in cases of full or mixed lubrication, or as microreservoirs for lubricant in cases of starved lubrication conditions. In both cases, friction is reduced, wear resistance is increased, and life is prolonged.

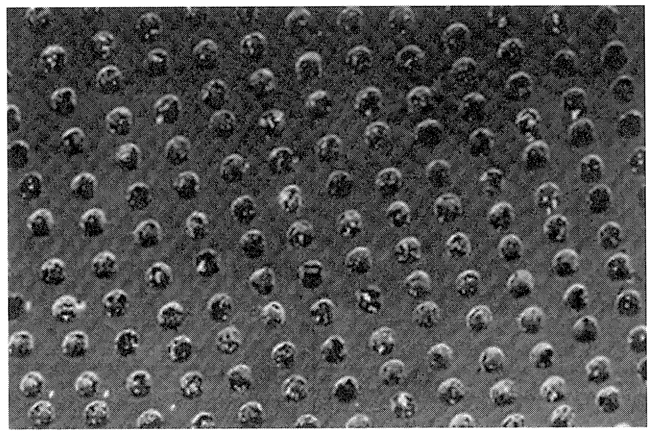


Figure 1. Regular Microsurface Structure in the Form of Micropores.

Etsion and Burstein (1996) presented a model for mechanical seals with regular microsurface structure showing a substantial improvement in seal performance when evenly distributed hemispherical micropores are present on one of the mating seal faces. This work was followed by an experimental study (Etsion, et al., 1997) in which laser-textured seal rings were tested in oil showing that the spherical pore shape can be optimized and that an optimum pore depth exists that maximizes the film stiffness and the maximum PV factor.

Based on the findings in Etsion, et al. (1997), a thorough investigation was performed in Etsion, et al. (1999), to study the various parameters that affect the performance of laser textured seal faces. The model of Etsion and Burstein (1996) was substantially improved to include more realistic boundary conditions, and to allow the analysis of various pore shapes, other then hemispherical.

Microsurface structures of other types were also suggested in the literature, e.g., microasperity lubricated face seals (Anno, et al., 1969) and various controlled porosity for mechanical seals (Heinrich, et al., 1991; Etsion and Michael, 1994). However, of all the practical microsurface patterns, it seems that the laser surface texturing (LST) is the most promising design. This is because the laser is extremely fast, clean to the environment, and provides excellent control of the shape and size of the pores that allow realization of optimum designs. Indeed, laser technology is starting to gain some attention in the mechanical seal community, as is evident from the proceedings of the 1997 International Fluid Sealing Conference where three laser related papers were presented (Etsion, et al., 1997; Muller, et al., 1997; and Antoszweski and Rokicki, 1997).

The present paper describes more experiments that were performed to demonstrate the potential of LST for improving performance of mechanical seals. Experience gained in field tests at several beta sites since May 1998 is also presented.

EXPERIMENTAL INVESTIGATION

The special test rig described in Etsion, et al. (1997), was used to demonstrate the LST effect on the maximum PV value at seizure inception of silicon carbide (SiC) rings running against carbon rings in water. A schematic description of the ring's specimen and mode of operation is shown in Figure 2.

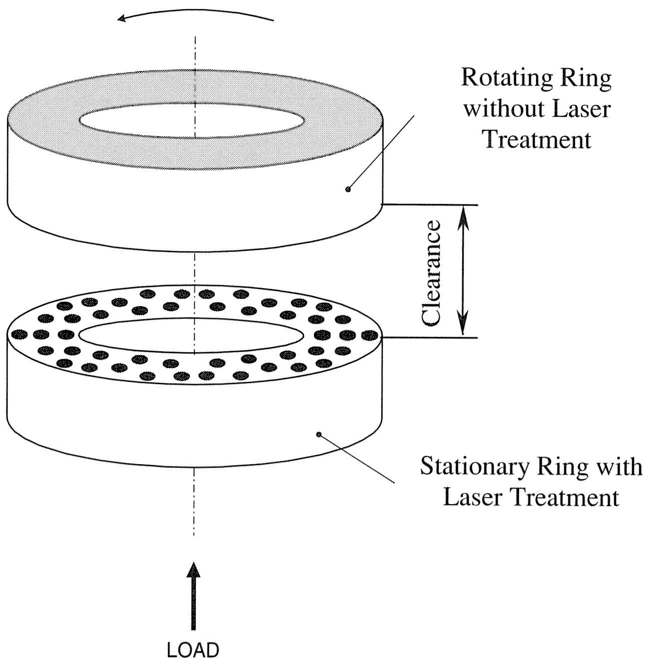


Figure 2. A Schematic of the Test Rings and Mode of Operation.

The inner and outer radii of the lower SiC ring and the upper carbon ring were 14 mm and 19.75 mm (0.55 in and 0.78 in), respectively. The upper ring can be rotated at different speeds from 300 to 5000 rpm, while the lower ring is loaded axially against it with gradually increasing loads. Water is supplied by gravity to the center of the lower ring and lubricates the interface between the two rings. Water was selected to demonstrate the feasibility of the concept even with poor lubricants with relatively low viscosity. The friction force between the mating rings can be measured to provide the seizure inception as the load reaches its critical value.

Figure 3 shows the results of a test performed at 4000 rpm. The average (shown by the darker bars) of the maximum PV value for three tests (shown by the lighter dotted bars) performed with the conventional untextured rings is about 0.6 MPa m/sec (17,142 psi ft/min). With laser-textured SiC rings having pores with a diameter of 95 μm (3.74 mil), evenly distributed with an area density of 20 percent, the average of the maximum PV values are about 2 MPa m/sec (57,142 psi ft/min) and 3 MPa m/sec (85,714 psi ft/min) for pore depths of 6 μm (0.23 mil) and 3.5 μm (0.14 mil), respectively. Hence, an increase of up to five times in seizure resistance is demonstrated with the LST technique.

The same test rig was also used to evaluate the LST in comparison with the alternative technology of "controlled porosity" SiC rings. Figure 4 presents the results of the friction force versus the normal load for standard, "controlled porosity" and optimized LST SiC rings against carbon mating rings in water. As can be seen, the controlled porosity ring results in about 10 to 15 percent lower friction than the standard one. With the textured ring, however, the reduction in the friction is much more substantial being from 65 to 75 percent.

Following the successful experiments on the test rig, an actual water pump was installed in the laboratory to allow tests with actual seals. The pump was circulating water from and into a 200 liter (52.8 gallon) container and its discharge pressure could be

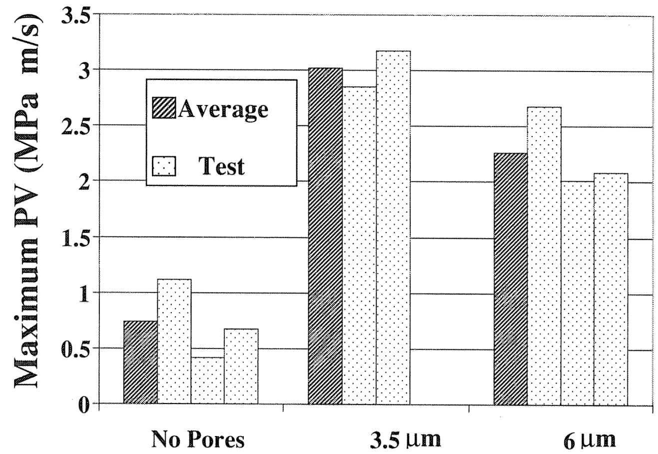


Figure 3. Maximum PV Values Before Seizure at 4000 RPM in Water.

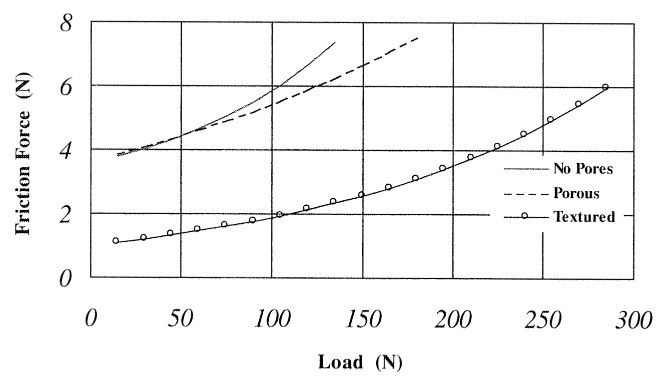
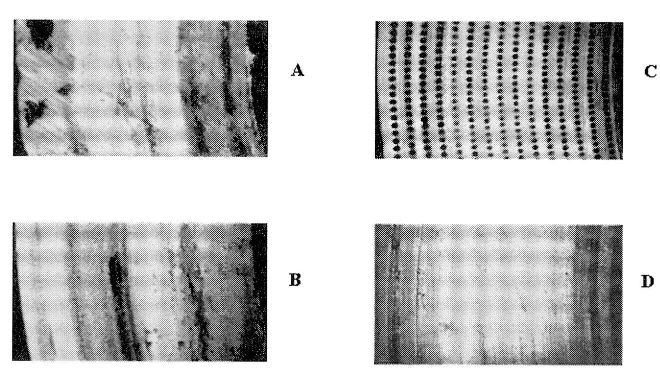


Figure 4. A Comparison of the Friction Force in Water for Untextured, "Controlled Porosity," and Laser Textured SiC Rings.

adjusted by a valve on the pump outlet. The seal was a single spring type with tungsten carbide (WC) mating rings sealing a 16 mm (0.63 in) shaft diameter at 3000 rpm. The pressure differential across the seal was 0.17 MPa (24 psi). Figure 5 shows the effect of LST on the wear of the mating faces as compared to the wear of untextured rings. The original seal rings with no pores exhibited appreciable wear marks and material transfer on their faces already after 200 hr in operation, while the faces of the textured pair appeared as they were new even after 500 hr in operation.



A + B - Mating rings of untextured seal after 200 hr test
C + D - Mating rings of textured seal after 500 hr test

Figure 5. A Comparison of the Face Wear of Untextured (After 200 Hours) and Textured (After 500 Hours) WC Mating Rings in an Actual Water Pump Seal.

A small seal manufacturer in Israel evaluated the LST under "flashing" condition using fresh water at elevated temperatures as the sealed media. The test setup is shown in Figure 6. It consists of a balanced seal with standard carbon-graphite for the rotating face and sintered SiC for the stationary face. The shaft diameter was 35 mm (1.38 in) and the rotational speed 3000 rpm. The water temperature and pressure were increased during the test from 97°C (207°F) and 0.2 MPa (29 psi) to 115°C (239°F) and 0.6 MPa (87 psi). First, a standard untextured seal was run for 46 days (accumulating over 400 hr) and then a textured seal was run under identical conditions and schedule. The total daily leakage was measured every day and the wear of the SiC rings at the end of the tests. Figure 7 presents the comparison of the daily leakage history for the textured and standard seals. The most significant result is the overall lower leakage of the textured seal. The mean of all the test points for the textured seal is about 42 cubic cm (2.56 in^3) per day compared to about 52 cubic cm (3.17 in^3) per day for the standard seal, representing about 20 percent lower leakage for the textured seal. Wear at the conclusion of the test was obtained from six equally spaced radial profilometer traces. The average wear of the standard SiC ring was 1.02 μm (0.04 mil), while that of the textured SiC ring was only 0.48 μm (0.019 mil). The textured seal maintained, over the test period, higher flatness and better surface finish of the mating rings as compared to the standard seal. This better mechanical integrity of the dynamic sealing interface of the textured seal over the test period may be responsible for its lower leakage.

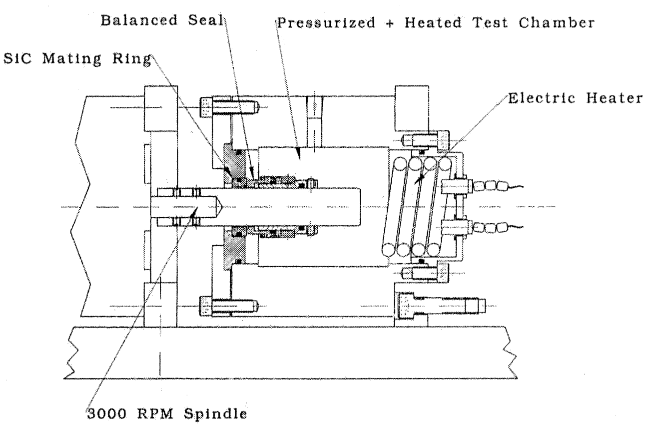


Figure 6. Test Setup for Seals under Flashing Condition.

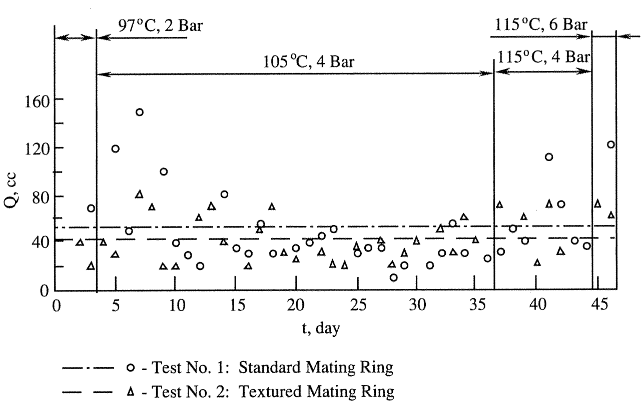


Figure 7. Comparison of the Leakage History for Textured and Untextured Seals under Flashing Condition.

A major seal manufacturer in the USA performed more extensive tests to compare various textured and standard seals' combinations of mating rings. Tests were performed in water at 3600 rpm and PV values from 116,000 psi-fpm to 414,000 psi-fpm. Figure 8 is an example of the torque versus face unit load results obtained with SiC/SiC mating rings' combination. As can be seen, the textured seal is most advantageous at the lower unit load range where friction torque reduction of up to 10 in-lbs can be obtained, representing about 65 percent reduction in energy consumption. The corresponding seal face temperature is shown in Figure 9 demonstrating up to 25°F cooler faces for the textured seal at the low unit load range. Longer tests at a maximum water pressure of 200 psi were also performed and Figure 10 is an example of the face temperature history over a 16 hr test. Note the gradual reduction in the face temperature of the textured seal reaching about 80°F after 16 hr as compared to 130°F in the untextured seal.

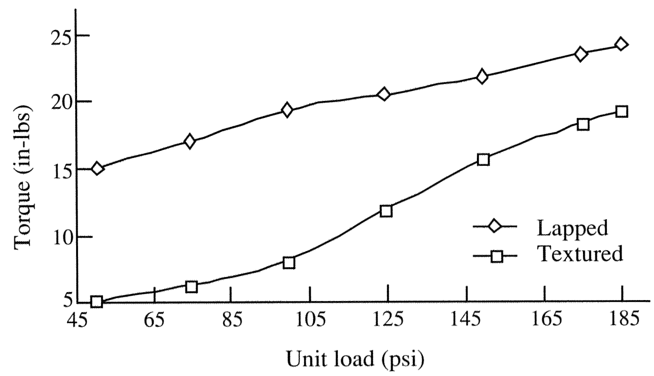


Figure 8. Comparison of the Friction Torque Versus Face Loading for Textured and Untextured SiC/SiC Seals in Water.

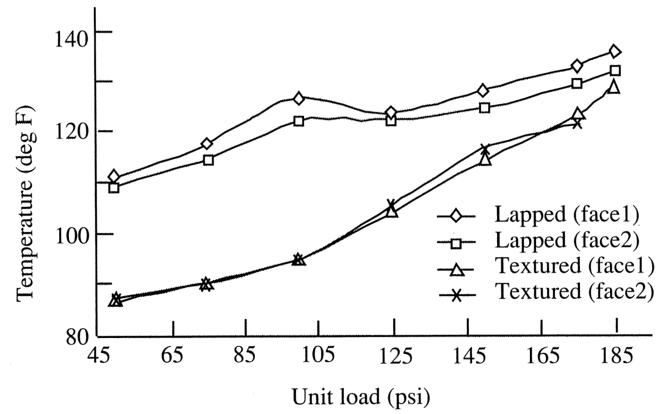


Figure 9. Comparison of the Face Temperature Versus Face Loading for Textured and Untextured SiC/SiC Seals in Water.

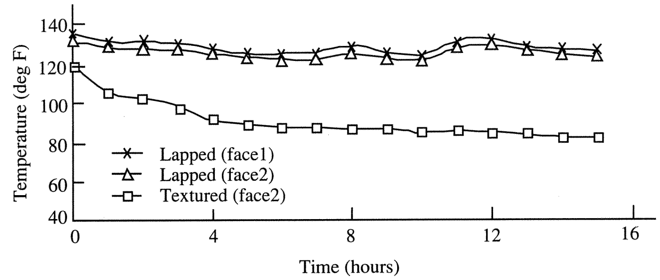


Figure 10. Comparison of the Face Temperature History at 200 PSI Face Loading for Textured and Untextured SiC/SiC Seals in Water.

FIELD TESTS

Table 1 presents some of the seals that are currently field tested in Israel. The first field test (#4 in Table 1) was started in May 1998 at a petrochemical industry. A standard seal having 88 mm (3.46 in) outer diameter and tungsten carbide/carbon (WC/C) mating rings was textured and installed in a 2900 rpm pump that pumps toluene at 229°C (444°F) to 1.63 MPa (256.4 psi). To date (August 1999), the seal has accumulated over 6000 hr in operation and is working satisfactorily.

Table 1. Details of Some of the Field Applications and Seal Data for LST Seal Tests.

#	Seal OD mm (in)	Face Materials	Speed rpm	Sealed Fluid	Pressure MPa (psi)	Temperature °C (°F)	Comments
1	65 (2.56)	WC/C	2900	Water	0.7 (101)	40 (104)	Acidic water
2	56 (2.20)	WC/C	3000	TSC [1]	0.14 (21)	60 (140)	20% slurry
3	56 (2.20)	WC/C	3000	Water	0	60 (140)	failed due to dry running
4	88 (3.46)	WC/C	2900	Toluene	1.36 (197)	229 (444.2)	
5	38 (1.49)	WC/C	2960	Light HC [2]	0.63 (91)	135 (275)	
6	87 (3.42)	WC/C	1450	AHCS [3]	0.12 (17)	172 (341.6)	
7	82 (3.23)	WC/C	2955	XHC [4]	0.87 (126)	266 (510.8)	
8	81 (3.19)	SiC/C	2950	PDB [5]	0.32 (46)	183 (361.4)	
9	62 (2.44)	WC/C	1480	Water	0.59 (85)	10-15 (50-59)	
10	78 (3.07)	WC/C	1500	Water	1.45 (210)	10-15 (50-59)	high sand level
11	78 (3.07)	WC/C	1490	Water	2.45 (355)	20 (68)	

[1] Tri Sodium Citrit
[2] Hydrocarbon
[3] Aromatic Hydrocarbon Sulfolane
[4] Xylen Hydrocarbon
[5] Para Diethyl Benzene

Since this first field test, numerous pumps in various industries in Israel are operating with LST seals. Seal sizes (outer diameter) range from 38 mm (1.49 in) to 88 mm (3.46 in), rotational speeds range from 1480 rpm to 3000 rpm, fluid pressures range from zero to 2.45 MPa (355 psi), and fluid temperatures from 10°C (50°F) up to 266°C (510°F). The variety of sealed fluids is also extensive, from water through various hydrocarbons to acids, both clean and up to 20 percent slurry. All the LST seals are functioning satisfactorily with the exception of one case (#3 in Table 1) where the outboard seal of a double seal configuration failed due to a dry running accident.

In some cases where a designated comparison was made between textured and untextured seal rings after about the same accumulating hours in operation, under identical conditions the integrity of the textured seal faces was always superior. One such example is shown in Figures 11, 12, 13, and 14. These figures present results obtained at the Israel national water company. The standard seal consisting of WC/C mating rings and having an outer diameter of 68 mm (2.68 in) is operating in a 1500 rpm water pump that pumps water at 10°C to 15°C (50°F to 59°F) to a discharge pressure of 1.95 MPa (282.8 psi). The water contains high levels of sand, causing severe wear and damage of the carbon ring and an extremely short life of about 400 hr. Figures 11 and 12 show the standard seal faces after 400 hr in operation and seal failure. The carbon ring damage is clearly visible and many wear marks on the WC ring can be seen. The textured seal (#10 in Table 1) operated under identical conditions for 550 hr with no problem before it was purposely removed from the pump for examination. Figures 13 and 14 show the WC ring textured face and its mating carbon ring after the 550 hr test. Clearly the carbon ring and the WC ring are in very good condition. The measured wear of these rings is only one-third that of the untextured rings. Also, the pores remain clean with no abrasives collecting in them. Although the textured seal was of a slightly different design, its rings were of identical materials. According to the technicians' experience with the particular pump, without the texturing it would perform similarly to the seal shown in Figures 11 and 12.

It should be noted that all the tests mentioned above were performed with standard contacting seals that were laser textured without altering their balance ratio. Further improvement can be obtained by properly tuning the balance ratio and LST parameters of textured seals to control the contact pressure between their mating faces. Noncontact operation is also possible with properly tuned LST seal rings.

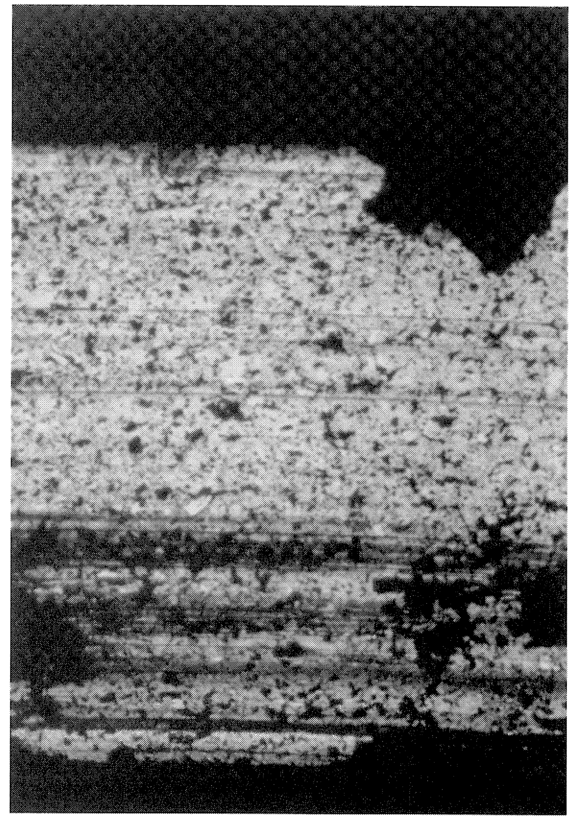


Figure 11. Face of the C Ring of an Untextured Seal after 400 Hours of Operation in Sandy Water.

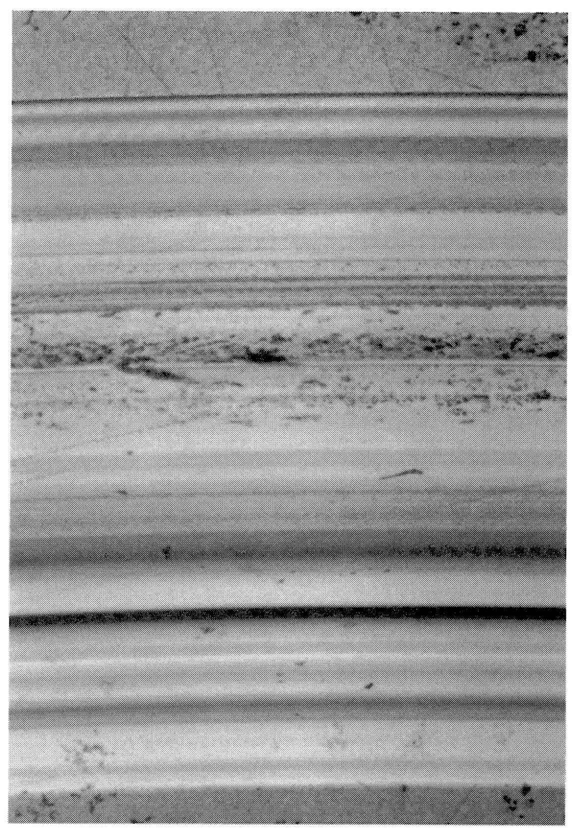


Figure 12. Face of the WC Ring of an Untextured Seal after 400 Hours of Operation in Sandy Water.

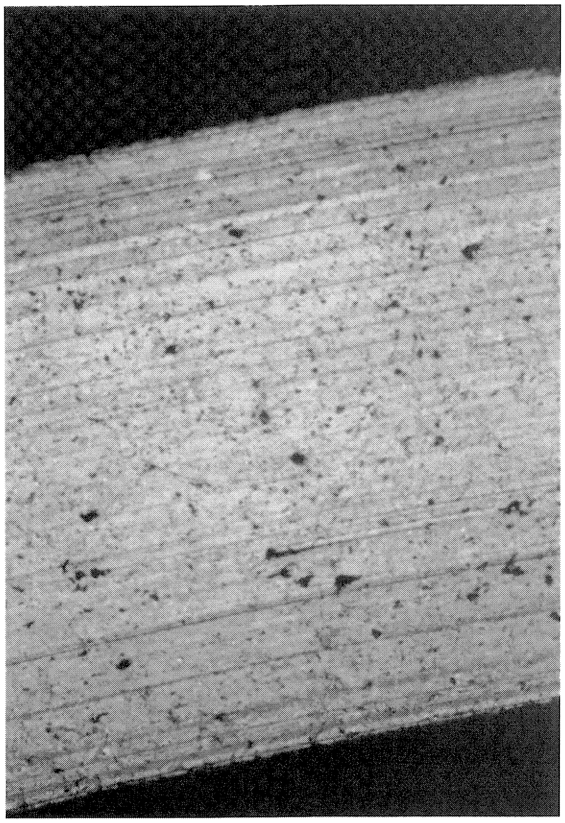


Figure 13. Face of the C Ring of a Textured Seal after 550 Hours of Operation in Sandy Water.

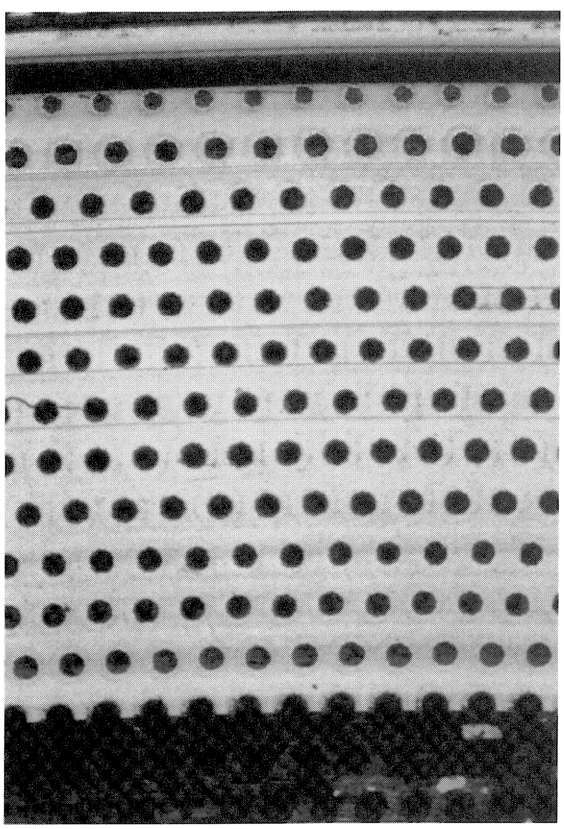


Figure 14. Face of the WC Ring of a Textured Seal after 550 Hours of Operation in Sandy Water.

CONCLUSION

Significant improvement in mechanical seal performance can be obtained by applying carefully engineered and controlled surface texturing to one of their mating ring's faces. The regular microstructure in the form of thousands of micropores provides hydrodynamic separating force and fluid film stiffness that prevents the mating surfaces from being exposed to severe contact pressure. This in turn reduces friction torque, face temperature, and wear rate. Thus resulting in better durability and integrity of the mating faces with better sealing capability and longer life.

Laser surface texturing (LST) technology has proved itself an efficient, fast, and accurate way of applying the regular microstructure to a seal ring face. It has been used both for laboratory and field tests and gave excellent promising results. Maximum PV factor before seizure has been increased five times and friction coefficient was reduced four times in laboratory testing with water. Other tests performed independently by two seal manufacturers showed similar reduction in friction torque, substantial reduction in wear rate and face temperature, and about 20 percent reduction in leakage. Field tests have also shown dramatic improvement in wear resistance. So far, thousands of hours have been accumulated in several petrochemical industries in Israel where textured seals are running satisfactorily.

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