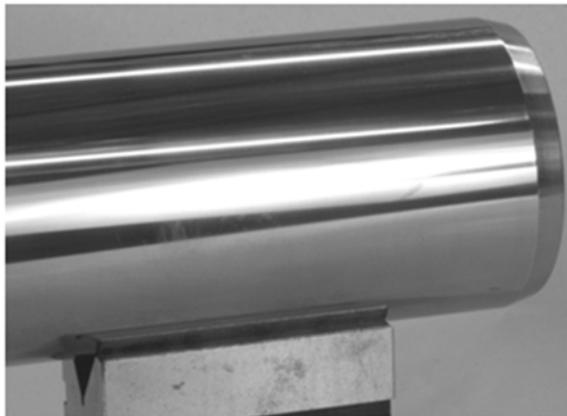


Chapter D2

The shaft running surface



Revision 5 August 6, 2019

Individual chapters of the Kalsi Seals Handbook™ are periodically updated. To determine if a newer revision of this chapter exists, please visit <https://www.kalsi.com/seal-handbook/>.

NOTICE: The information in this chapter is provided under the terms and conditions of the Offer of Sale, Disclaimer, and other notices provided in the front matter of this handbook.

1. Diameter of the shaft sealing surface

For the best abrasion resistance, size the sealing surface of the shaft to match the approximate as-molded seal inside diameter (see the [website](#), or call Kalsi Engineering). If the shaft is significantly smaller than the inside diameter of the seal, the resulting increased circumferential seal compression may promote skew-induced wear¹ or other issues. If the shaft is significantly larger than the inside diameter of the seal, circumferential tension may cause cross sectional twisting or other issues, such as reduced compression or grabbing of the shaft. Figure 1 shows achievable tolerances for ground shafts.

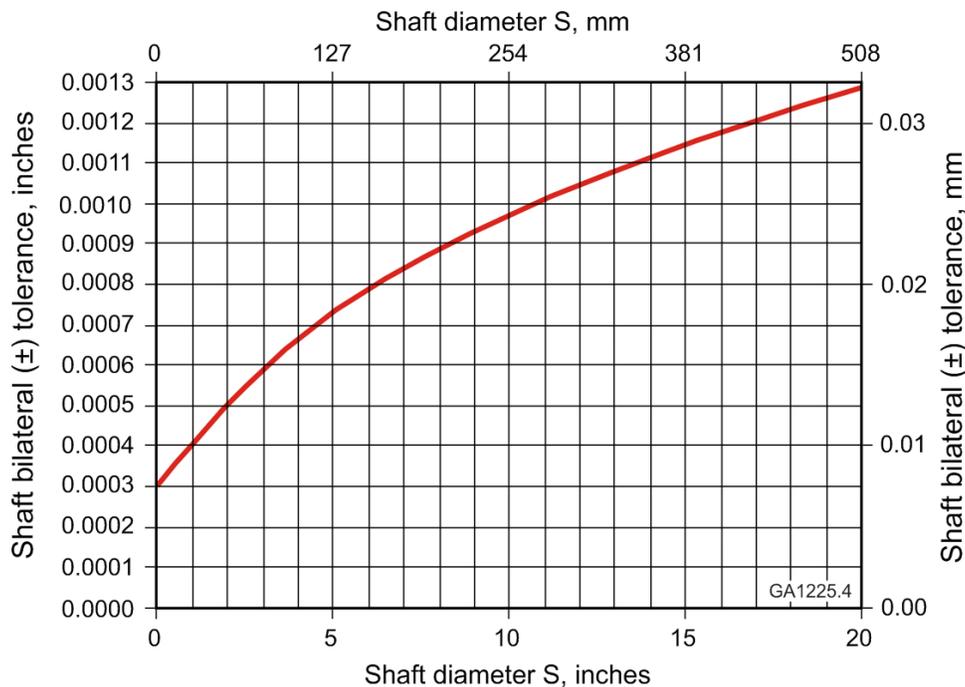


Figure 1
Achievable tolerances for ground shafts

This graph conveys readily attainable grinding tolerances, and is not seal performance based. The intent is to provide machine designers with general guidance in establishing reasonable tolerances.²

¹ See Chapter D9 for a description of skew induced abrasive wear.
² The basis for the graph is Figure 2.11 of the book "Technical Drawing", Seventh Edition, by the Macmillan Publishing Co. See that book for practical tolerances for other manufacturing methods.

2. Shaft surface finish roughness

Kalsi Seals[®] are designed to run on a smooth, hard shaft surface (Figure 3) and we typically recommend ground and polished tungsten carbide. The seal contact location must be kept free of flaws such as cracks, dings, wear and corrosion. For best results on small diameter shafts, use a ground and polished surface finish of 4 μin (0.10 μm) AA³ or less for general purpose use, and 2 μin (0.05 μm) AA or less for severe service use.⁴ Examples of severe service include high differential pressure, high temperature applications, or applications that use low viscosity⁵ lubricants. Even glass smooth is acceptable, because Kalsi Seal[™] rotary performance is not dependent on retention of oil by the shaft surface finish. During initial development, Kalsi Seals were actually tested on a glass surface, in order to observe and measure film thickness.

Since surface texture is dependent on manufacturing process, shaft drawings should designate “fine grinding” or “diamond grinding” in addition to the usual surface finish symbol (Figure 2). Avoid vendors who achieve the designated surface finish by filling in the porosity of the tungsten carbide coating with a plastic coating.

As shaft diameter increases, it becomes less practical to achieve a 2 to 4 micro-inch AA finish. Our tungsten carbide coating vendor uses 3M brand 9 micron diamond lapping paper for the final polishing of the ground tungsten carbide coated shafts used in our lab testing (Figure 3). A surface finish of 2 μin (0.05 μm) AA or less is typically achieved on 2.75” shafts. A surface finish of 7 μin (0.18 μm) AA or less is typically achieved on 10.50” shafts.

The surface finish lay should be perpendicular to the shaft axis, rather than spiral, if possible. Spiral lead can potentially pump fluid past the rotary seal. If spiral lead is unavoidable, then orient it to pump lubricant past the seal, and to oppose environmental invasion.

³ The surface finish roughness arithmetic average (AA) is also known as roughness average (Ra). The 4 micro-inch AA recommendation is the result of solving a seal performance issue by switching from an 8 to a 4 micro-inch AA finish. The larger the allowed average roughness value, the easier it is for the average to mask a sizable defect.

⁴ We reviewed the surface finish measurements from 35 2.75” (69.85mm) diameter test sleeves from our rotary seal test fixtures, and found that the average Ra for all the sleeves was 2 micro-inches, with a range of 1.3 to 3.3 micro-inches Ra. The average Rz for all 35 sleeves was 27 micro-inches, with a range of 16.1 to 49.2 micro-inches Rz.

⁵ Viscosity is a measure of resistance to flow. Low viscosity lubricants are thinner, and less resistant to flow. High viscosity lubricants are thicker, and more resistant to flow.

For best results, use an electronic profilometer (Figure 4) to inspect the surface finish on all new and refinished shafts. If a profilometer is unavailable, surface finish can be estimated using a surface finish comparison standard (Figure 5).⁶

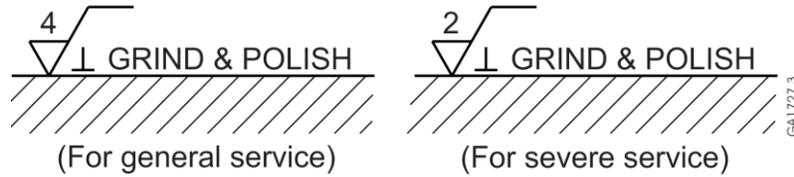


Figure 2

This graphic shows a typical inch-type surface finish symbol applied to the shaft running surface, for use with a Kalsi Seal. The left-hand example specifies that the ground and polished surface have no more than 4 micro-inches (0.10 μm) AA roughness, with the surface finish lay oriented perpendicular to the drawing cross section (i.e. oriented circumferentially around the shaft). In our experience, surface finish requirements must be relaxed as shaft diameter increases.

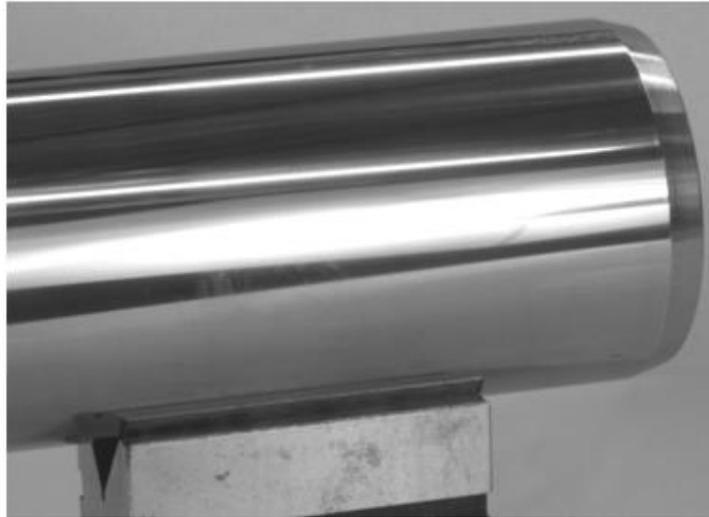


Figure 3

Example of a ground and polished tungsten carbide coated shaft

This smooth surface finish is the result of grinding, and then polishing with 3-M brand 9 micron diamond lapping paper. Achieving a smooth surface finish is especially important for severe service applications (such as high differential pressure operation), to minimize asperity contact between the seal and the rotary shaft.

⁶ A person can typically detect a surface finish of 16 micro-inches and above by dragging their fingernail across the lay of the surface.



Figure 4
Inspect shaft surface finishes with a profilometer

This photo illustrates use of a profilometer to inspect the surface finish of a shaft. The instrument provides a printout of detailed surface finish profile information.

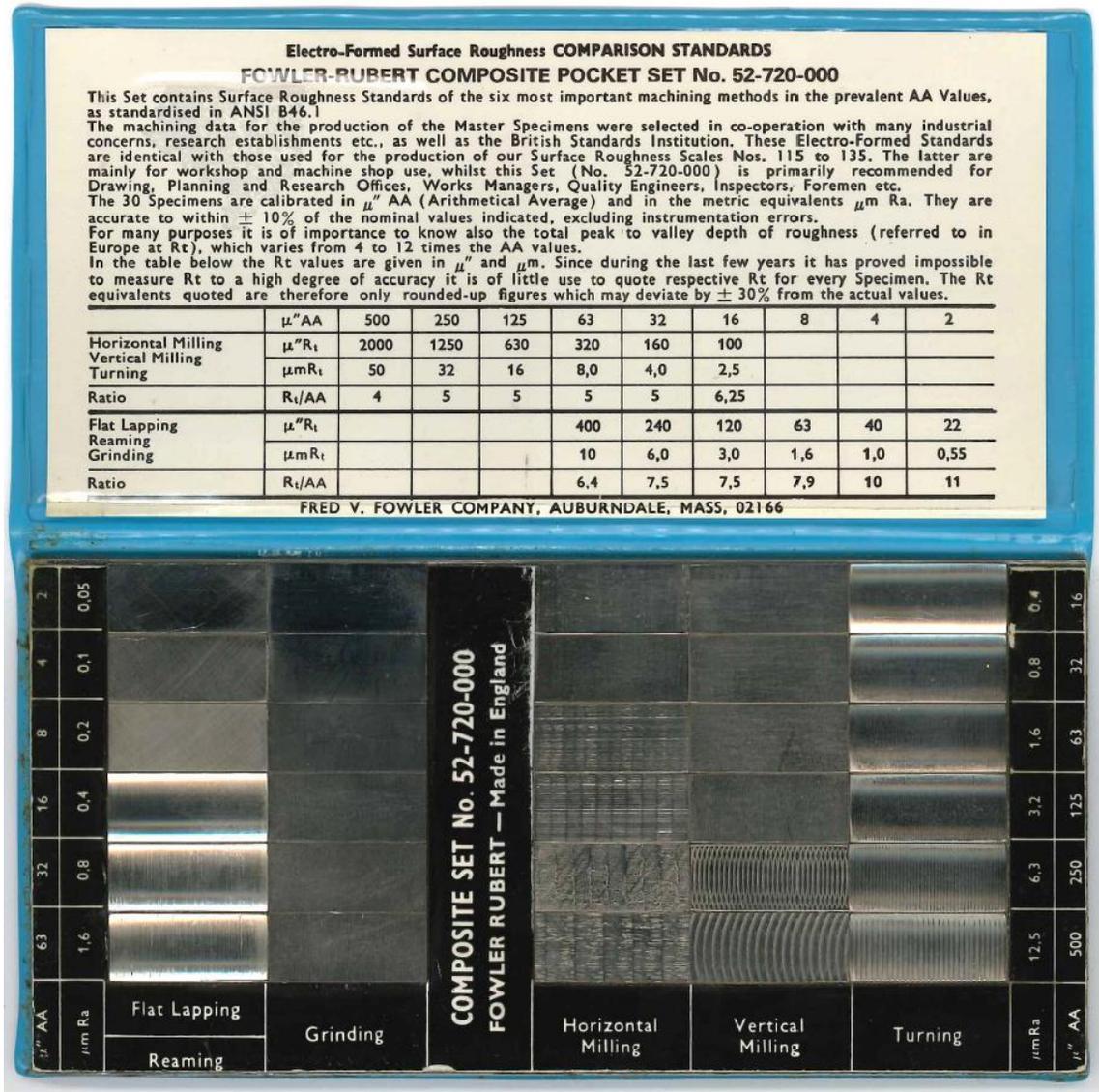


Figure 5
Surface finish comparison standard

In the absence of an electronic profilometer, a surface finish comparison standard can be used to estimate surface finish.

Avoid grinding chatter

Eccentric grinding wheels, and other causes of grinding vibration, can cause surface faceting known as grinding chatter (Figure 6). Avoid chatter in rotary shaft seal applications, because it may cause accelerated leakage and environmental invasion. Even though grinding chatter causes only a small roundness deviation, its repetitive nature can cause high frequency seal compression fluctuations that exceed the response capability of the seal. This can create a path for lubricant loss and environmental invasion. Leakage related to grinding chatter may increase at lower temperatures, due to slower elastomer dynamic response characteristics.

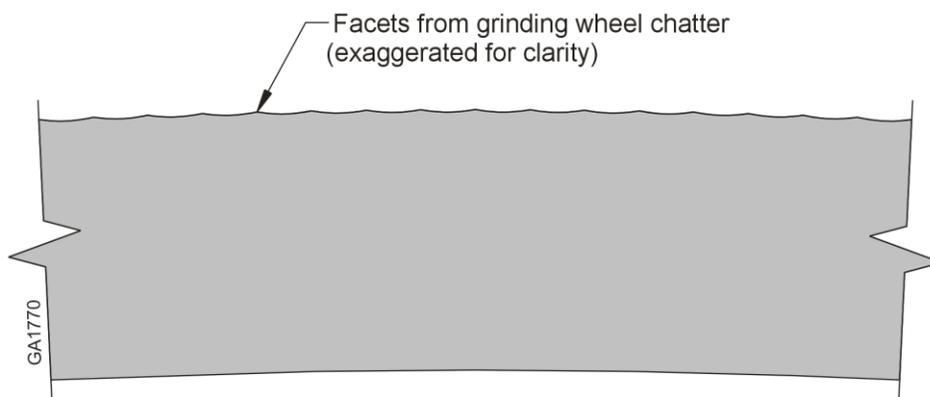


Figure 6
Avoid grinding wheel chatter

An eccentric grinding wheel produces longitudinal facets on the shaft. At high speeds, a rotary shaft seal cannot follow the facets, resulting in higher lubricant leakage. Such facets may reduce environmental exclusion.

3. Tungsten carbide shaft coatings for abrasive service

An abrasion resistant treatment applied to the shaft sealing surface prevents premature shaft and seal wear, especially when environmental abrasives are present. Premature shaft wear reduces rotary seal compression, abrades the seal directly, and promotes ingestion of environmental abrasives.

Shaft wear can also occur at the extrusion gap between the seal housing and the shaft due to abrasive entrapment in the extrusion gap (Chapter D7). This type of wear can progress axially and undermine and abrade the rotary shaft seal. Such undermining accelerates with softer shaft treatments such as nitriding (Figure 9) and carburizing.

Appropriate surface treatment reduces shaft wear. Of the various shaft treatments tested by Kalsi Engineering, high-velocity nickel-based tungsten carbide spray coating

provides the best wear resistance by far, and is our preference for both abrasive and nonabrasive applications.

The corrosion resistance of tungsten carbide compositions must be considered. In our experience, nickel-based compositions hold up well in oilfield downhole conditions. Cobalt-based compositions can corrode rapidly in some types of drilling fluids, leaving a roughened, highly abrasive surface (see Figures 7 and 8). Consult with your tungsten carbide vendor for the most appropriate composition for your operating environment.



Figure 7
Corroded cobalt-based tungsten carbide coated sealing surface

After just 50 hours of boring through limestone and ash formations, corrosion from exposure to drilling fluid permanently damaged the finely ground cobalt-based tungsten carbide sealing surface⁷ of this mud motor mandrel, leaving it unusable. Drilling fluid contacted the portion of the tungsten carbide at location 'L', while bearing lubricant protected the location at 'K'. The polished Kalsi Seal running track can be seen just to the right of location 'K'.

⁷ The corroded coating shown in Figure 7 was specified as 84 to 89% tungsten carbide, 7 to 11% cobalt, 3 to 4% chrome, and 0 to 5% carbon, with a hardness of 65 to 72 Rockwell C. Although we have not used this composition for many years, we considered its performance to be acceptable in applications that did not cause corrosion of the composition.

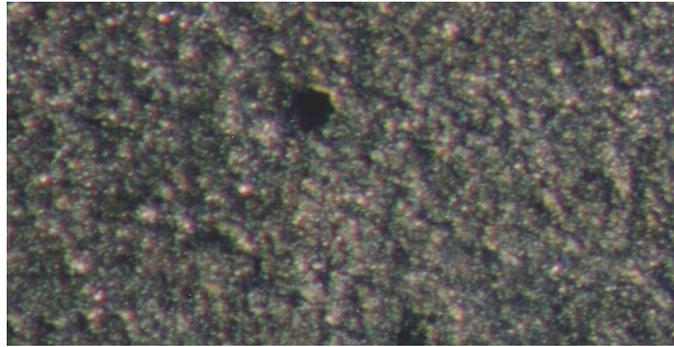


Figure 8
Ground cobalt-based tungsten carbide coated sealing surface
corroded by exposure to oilfield drilling fluid (Scale: 70X).

This is a magnified view of the corroded portion of the tungsten carbide coated mud motor mandrel that is shown in Figure 7.

Kalsi Engineering uses the following nickel-based tungsten carbide specification⁸ for rotary shaft seal testing:

Coating Composition:	90% Tungsten Carbide 10% Nickel
Coating Hardness:	Approx. 70 Rockwell C
Tensile Bond Strength:	10,000 psi minimum
Metallographic Apparent Porosity:	1% maximum
Finished Coating Thickness:	0.005” to 0.015” (0.13 to 0.38 mm) Check with the coating vendor for thickness preference.
Surface Finish:	4 µin AA (0.10 µm AA) or less for general service; use 2 µin AA (0.05 µm AA) or less for severe service ⁹ .
Machining Method:	Diamond Grinding
Avoid phosphate-based cleaners and rust inhibitors.	

⁸ This composition has greater abrasion resistance and less porosity than the nickel-chrome composition that was shown in Revision 0 of this handbook, and facilitates a smoother finish. The addition of chrome to a tungsten carbide matrix increases the porosity and resulting surface finish roughness of the coating. Kalsi Engineering uses the recommended coating on AISI 4140/4150 sleeves that are routinely used in 162 to 400°F (72.2 to 204.4°C rotary tests. Neither Kalsi Engineering nor its grinding vendor has observed corrosion of the recommended coating in oilfield service.

⁹ Examples of severe service conditions include high differential pressure, low viscosity lubricants, and high operating temperature.

According to our tungsten carbide coating vendor, the temperature of the part being coated by high-velocity deposition generally does not exceed 275 to 300°F (135.0 to 148.9°C), and part temperatures higher than that will negatively affect the quality of the coating. This means that the deposition process does not affect the strength of steel parts.

Many different metals can accept a tungsten carbide coating, provided the coefficients of thermal expansion between the coating and the part do not differ grossly, and hardness of the coated part is below 50 Rockwell C. Prior to coating, the surface receives a grit or bead blasting to roughen it, and to remove any oxide layer that may exist. (It is difficult to adequately roughen the surface of parts that are harder than 50 Rockwell C.) An adequately rough surface is necessary to achieve good adhesion between the coating and the component being coated. The coating only adheres to the surface of the part. There is virtually no intermingling of the base material and the coating. If this mixing occurs, it is not possible to achieve the desired coating properties (hardness, porosity, etc.). Because the coating and substrate do not “mix”, material compatibility issues are limited.

Recommended tungsten carbide coating thickness

The tungsten carbide coating specification indicates a coating thickness of 0.005” to 0.015” (0.13 to 0.38 mm). Use the tungsten carbide thickness your coating vendor recommends. Some vendors prefer to apply a thick coating, while others like to apply a thin coating. We use a thickness recommendation of 0.005” to 0.015” to cover the vendor thickness preferences we have encountered over the years.

Cloudiness

In years past, we experienced cloudiness of newly ground and polished tungsten carbide coated surfaces that had been oiled and wrapped with protective plastic or foam by our coating vendor. We performed rotary seal testing to see if the cloudiness impacted seal performance, but the testing was inconclusive.

We discussed the cloudiness with our vendor. They stopped oiling the parts and began using either vapor phase corrosion inhibitor paper or heavy-duty paper towels underneath the protective plastic or foam wrapping. This practice eliminated the cloudy appearance of the polished tungsten carbide surface.

Ensure that you and your vendors avoid cleaning solutions that deposit solids on the shaft, such as phosphate based cleaner/rust inhibitors. Phosphate based cleaners are known to cause significantly higher seal running torque and accelerated seal wear. Anyone who assembles and disassembles tools that use Kalsi Seals should read Chapter D19 of the handbook. A portion of Chapter D19 discusses the cleaning of parts. We use

a water-soluble cleaning solution and/or isopropyl alcohol to clean the hardware used in lab testing of rotary shaft seals.

Addressing worn tungsten carbide surfaces

The sealing surface of the shaft is a key part of sealing functionality. A rough, worn surface encourages seal slippage, adhesive wear, and third body wear, and increases seal generated heat. Maintenance of the shaft surface is an important part of equipment maintenance, and original equipment manufacturers should establish a maintenance process that allows worn shafts to be refurbished.

Shafts with worn sealing surfaces eventually need to be stripped, reground, and polished. When the surface finish of a tungsten carbide coated shaft initially begins to degrade,¹⁰ honing and polishing typically can eliminate the wear track¹¹ and restore the recommended surface finish. The honing process involves the removal of a few ten-thousandths of an inch of material, allowing the part to remain within tolerance. Even without honing, polishing with diamond-coated abrasive cloth can sometimes help restore roughened surfaces to the recommended finish. With either method, it is not necessary to replace the tungsten carbide during every rebuild.

With the larger cross-section seals that are typically used in many applications, honing the shaft down by even as much as 0.002 or 0.003” has very little practical effect on seal compression.

4. Shaft surface treatments for nonabrasive service

We prefer ground and polished tungsten carbide

We prefer ground and polished nickel-based tungsten carbide coating from a performance standpoint, even for nonabrasive service. Nevertheless, some customers may wish to evaluate less expensive coatings for cost sensitive, nonabrasive service applications.

¹⁰ At what surface roughness arithmetic average should the sealing surface of a shaft be reprocessed? Surface finish is a complex attribute to measure and describe, and surface roughness arithmetic average is far from being a comprehensive measurement. Still, to state a number as a general guideline, we recommend refinishing if the running track of the seal exceeds 8 micro-inches, arithmetic average.

¹¹ We do not provide a recommended allowance for wear track depth, because of the potential but unknown effects of the overall profile of the wear track, and the general lack of information on all the possible implications of running on a wear track of measurable depth. Instead, we recommend honing, to eliminate the wear track altogether.

Nitriding and carburizing

Suitably finished nitrided or carburized surfaces, can be useful in nonabrasive environments, but will groove in abrasive environments, potentially undermining the rotary seal (Figure 9).

Ground hard chrome

Ground hard chrome may have utility in nonabrasive applications; however, some hard-chromed surfaces can produce increased torque. Achieving adhesion between the chrome and the base metal can be difficult if silicone-based cutting fluids are used during lathe turning operations prior to plating. Silicone is difficult to remove, and some chrome plating vendors routinely sand blast before plating as a precaution.

Hardide

Hardide¹² has been tested with -10 and -11 seal materials, and has demonstrated utility in *nonabrasive* applications. The -10 tests were with an ISO 32 viscosity grade lubricant at 15 psi (103.4 kPa), at 162 to 300°F (72.2 to 148.9°C). The -11 seals were tested with an ISO 320 viscosity grade lubricant at 15 to 1,500 psi (103.4 kPa to 10.34 MPa), at 162°F (72.2°C). Torque values and hydrodynamic pumping related leak rates were within the range typical of seals running on surfaces coated with nickel-based tungsten carbide. Sleeve surface finishes ranged from 2 to 7 micro-inches RA (0.05 to 0.18 μm). The testing indicates a correlation between smoother surface finishes and lower running torque.

Bare steel is an unsuitable running surface

Our testing shows that bare steel, without any form of surface hardening, is unsuitable as a running surface for Kalsi-brand rotary shaft seals. The testing was performed with Plastic Lined SealsTM operating at low differential pressure and a relatively high hydrodynamic pumping related lubricant leak rate. Despite the high level of lubrication, the bare steel shaft experienced wear in the seal running track.

Avoid chromium oxide coatings

Avoid chromium oxide coatings, which have a microstructure that can be extremely damaging to rotary shaft seals.

¹² Hardide is the trademarked name of a proprietary coating of Hardide Plc, (Bicester, Oxfordshire, United Kingdom, and Houston, Texas).

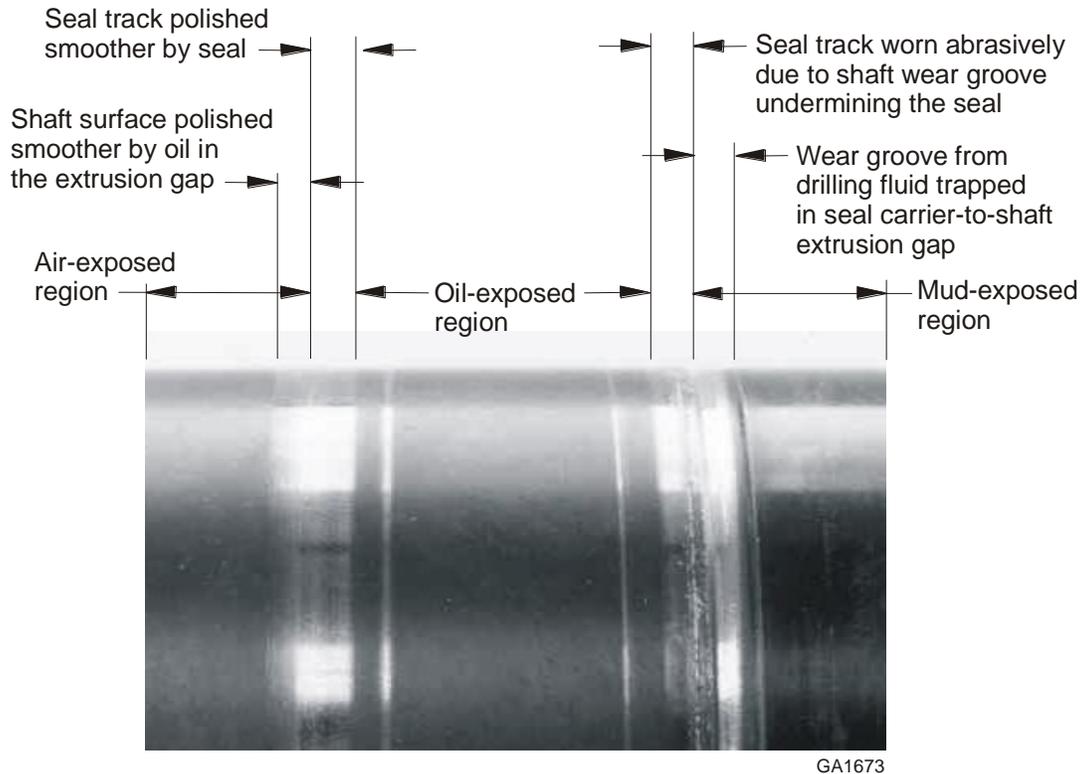


Figure 9
Nitrided surface worn by drilling fluid

Although nitriding can provide a suitable seal running surface for nonabrasive applications, abrasive applications can damage it. We tested this 2.75" (69.85 mm) rotary shaft at 480 rpm for 276 hours, with a lubricant pressure of 1,000 psi. The shaft was manufactured from Nitralloy 135.¹³ The surface of the shaft was hardened with a liquid nitriding process advertised to produce a hardness of at least 60 Rockwell C.¹⁴ The right-hand seal was exposed to a drilling fluid environment at atmospheric pressure, and the left-hand seal was exposed to the atmosphere. The drilling fluid was 9 lb/gallon, with a 1.5% sand content. The abrasives in the drilling fluid grooved the shaft at the right-hand extrusion gap between the shaft and the seal carrier. The groove was beginning to undermine the exclusion edge of the right-hand seal, which eventually allowed abrasives to enter the seal track and cause wear to the seal and shaft. With a nonabrasive environment, the left-hand seal polished the left-hand seal track to a smoother finish.

¹³ Nitralloy 135 is a trademark of Latrobe Specialty Steel Company, Latrobe, Pennsylvania.

¹⁴ A graph compares the Brinell hardness scale to the Rockwell B, C, R and M scales in the "**Wear Control Handbook**", American Society of Mechanical Engineers, New York, NY, 1980.