# TECHNICAL BULLETIN

## Surface Finish Recommendations & Coatings

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In case you have questions please contact: Trelleborg Sealing Solutions Fort Wayne
Product Engineering Department

# Surface Finish Recommendations & Coatings

## Contents



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# Surface Finish Recommendations & Coatings

## Introduction

Over the years Trelleborg Sealing Solutions has developed an in-depth knowledge of material technology to support customers. It is important to consider all parameters that influence a sealing system. Design factors such as hardware material, surface finish, operating conditions and seal geometry are all interdependent variables that must be optimized to ensure proper functions of the sealing system. The basic requirements for sealing counter surfaces are hard and free of scores, scratches, pores and machining marks.

This document contains detailed recommendations from TSS Fort Wayne Product Engineering for defining surface finish, suggested roughness testing methods, preferred hardware surface finish, material, coating/plating, hardness and machining methods. The purpose of these recommendations are to ensure the sealing system will function as effectively as possible.

## Surface Finish

Surface finish quality relates directly to seal performance. The optimum profile consists of valleys for lubrication and avoids a high concentration of peaks. Pockets and valleys are needed to build up a sufficient fluid film to reduce friction and wear, while a high concentration of peaks can cause excessive seal wear. Properly defining and controlling surface finish is critical to the functional reliability and life of a seal.

How to define surface finish? **The $R_a$ value is simply not enough to properly define surface finish**. The images in Figure 1 below highlight why $R_a$ is not enough to define the quality of a surface. The $R_a$ values are all similar, but only the top image is an optimum surface profile for sealing counterparts. A combination of surface measurements must be considered. The following parameters are required to capture a good understanding of the surface topography:

- $R_a$ = Arithmetical mean roughness value
- $R_p$ = Maximum Profile Peak Height
- $R_z$ ($R_{tm}$) = Mean roughness depth
- $t_p$ ($R_{mr}$) = Profile Bearing Ratio
- $R_{sk}$ = The degree of skew
- $R_t$ ($R_{max}$) = Total height of roughness profile

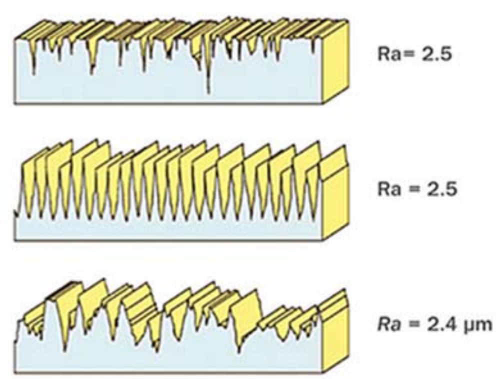
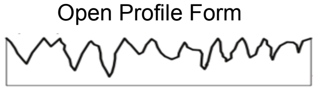



**Figure 1. Surface Comparison with same $R_a$**

# Surface Finish Recommendations & Coatings

## Surface Finish

The bearing ratio (material contact area), $t_p$ ($R_{mr}$), is also essential for determining surface quality. Figure 2 shows two surface profiles, both of which exhibit nearly the same $R_z$ values. The differences in surface profiles are evident by the bearing ratio.

| Surface Profile (µm) | $R_a$ | $R_z$ | $R_{mr}$ |
|---|---|---|---|
| Closed Profile Form  | 0.1 | 1.0 | 70% |
| Open Profile Form  | 0.2 | 1.0 | 15% |

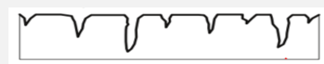
| Surface Profile (µin) | $R_a$ | $R_z$ | $R_{mr}$ |
|---|---|---|---|
| Closed Profile Form  | 4.0 | 40 | 70% |
| Open Profile Form  | 8.0 | 40 | 15% |

**Figure 2. Profile forms of surfaces**

A closed profile form is preferred over an open profile form because it is void of a high concentration of peaks. The mating surface must also have adequate valleys for the formation of a fluid film. The seal rides on the fluid film reducing friction and increasing seal life.

The seal in most cases will polish its mating surface. In Figure 3, the peaks on the counter surface are broken away during the initial start-up or break-in period. Theoretically the seal will run on a mating surface at 25% $R_z$ for the majority of its service life as shown in Figure 4.

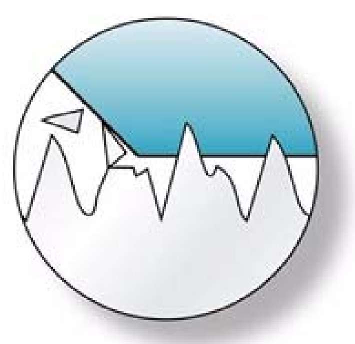


**Figure 3. Break-in phase**

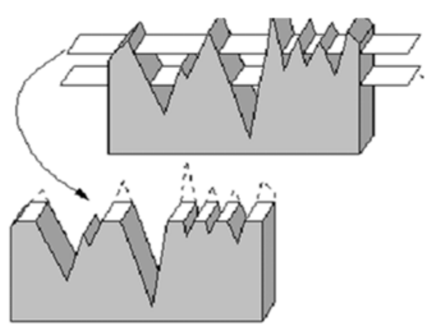


**Figure 4. Mating surface after break-in**

# Surface Finish Recommendations & Coatings

## Surface Finish

The material ratio $R_{mr}$ (ASME: bearing length ratio $t_p$) is the ratio expressed in percent of the material-filled length to the evaluation length $l_n$ at the profile section level c. Figure 5.

$$\mathbf{R_{mr}} = \frac{1}{l_n}(L_1 + L_2 + ... + L_n)\ 100\ [\%]$$

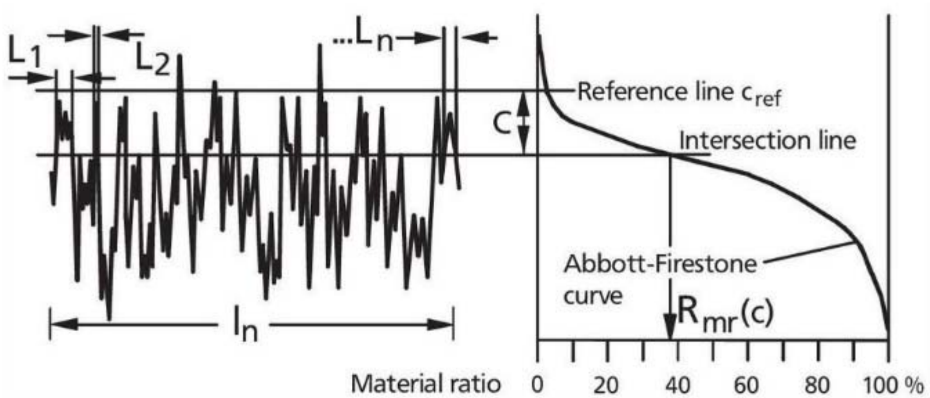



**Figure 5. Abbot-Firestone curve**

The bearing ratio is determined at a cut depth of c = 0.25 $R_z$ relative to the reference line of C ref = ( ) % based on the material/coating of the mating surface. Figure 6.

| Reference Line *c* | Material |
|---|---|
| 5% | Soft coatings, Chrome and HVOF |
| 2% | Nitrated and hardened |
| 0% | Ceramic coating |

**Figure 6. Reference line offset for bearing ratio**

# Surface Finish Recommendations & Coatings

## Testing Methods

Surface roughness can be measured using a contact or non-contact profilometer. A contact profilometer requires a contact stylus to measure surface roughness. The results depend on the stylist and scan length. A non-contact profilometer utilizes white light interferometry to characterize the surface topography in 2D or 3D. Defining the surface topography with a non-contact profilometer is the preferred method of testing.

Contact profilometry is more commonly used in the industry due to its lower cost. Figure 7 is the standard TSS R&D Americas recommendation for roughness testing on a Taylor Hobson TalySurf50.

| Contact Profilometer Setup for Roughness Measurement | | | | | | |
|---|---|---|---|---|---|---|
| ISO 4287 Parameters | Tip Size & Material | Cone Angle | Scan Length | Cut off Length | | Number of Measurements |
| $R_a$, $R_z$, $R_t$, $R_p$, $R_{sk}$ | 2 µm Diamond | 60° | 0.8 mm | ISO 4288 | ISO 3274 | 4 measurements 90° apart |

**Figure 7. Suggested method**

## Surface Finish Recommendations

Recommendations for surface finish are mainly based on the application, media, mating surface type and seal material. Figure 8 defines the critical surfaces that affect the seal for rod and piston applications.

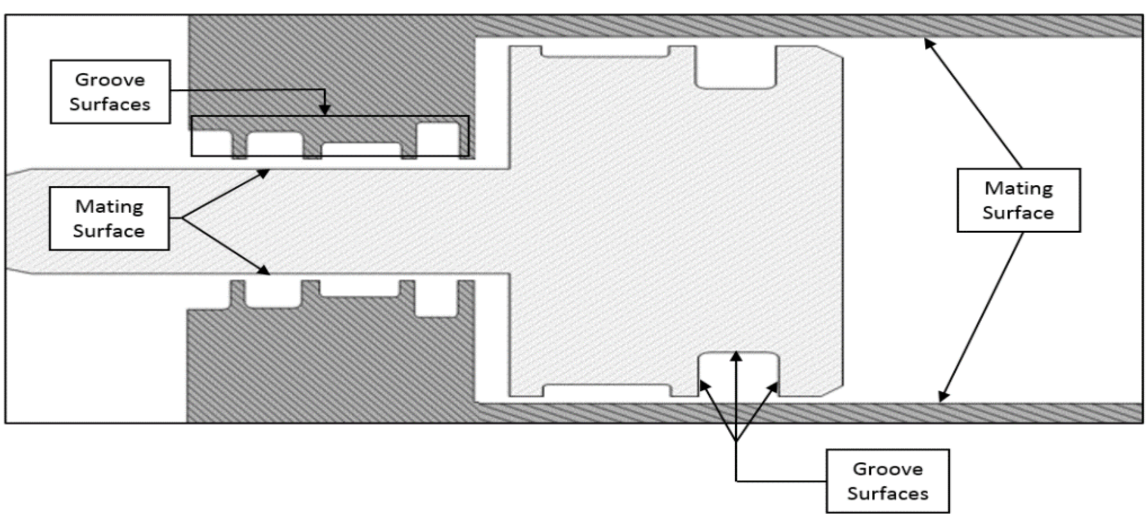



**Figure 8. Critical Surfaces**

# Surface Finish Recommendations & Coatings

## Linear Applications – Mating Surface

### Turcon® Slipper Seals

| Chrome plating, Anodized Surfaces, Bare Metals (Hardened) and others (Non-HVOF) | | |
|---|---|---|
| Parameter | Standard Mating Surface Finish | |
| | Inch (µin) | Metric (µm) |
| $R_a$ | 2 - 8 | 0.05 - 0.20 |
| $R_p$ | 24 max. | 0.60 max. |
| $R_z$ ($R_{tm}$) | 40 max. | 1.00 max. |
| $R_{sk}$ | -0.5 to -1.5 | |
| $T_p$ ($M_r$) | 50 - 75% @ depth of p = 0.25 $R_z$ ($R_{tm}$), reference line c = 5%$T_p$ | |

| HVOF Applied Surfaces [1] | | |
|---|---|---|
| Parameter | Standard Mating Surface Finish | |
| | Inch (µin) | Metric (µm) |
| $R_a$ | 2 - 5 | 0.05 - 0.12 |
| $R_p$ | 8 max. | 0.20 max. |
| $R_z$ ($R_{tm}$) | 40 max. | 1.00 max. |
| $R_{sk}$ | -0.1 to -3.0 | |
| $T_p$ ($M_r$) | 70 - 90% @ depth of p = 0.25 $R_z$ ($R_{tm}$), reference line c = 5%$T_p$ | |

### Zurcon® and Elastomer Seals

| Standard Mating Surface Finish | | |
|---|---|---|
| Parameter | Inch (µin) | Metric (µm) |
| $R_a$ | 4 - 16 | 0.10 - 0.40 |
| $R_z$ ($R_{tm}$) | 25 - 60 | 0.63 - 2.50 |
| $R_t$ ($R_{max}$) | 40 - 100 | 1.00 - 4.00 |
| $T_p$ ($M_r$) | 50 - 75% @ depth of p = 0.25 $R_z$ ($R_{tm}$), reference line c = 5%$T_p$ | |

### Groove Surfaces all Materials [2]

| Parameter | Surface Finish Max. | |
|---|---|---|
| $R_a$ | 63 µin | 1.6 µm |

# Surface Finish Recommendations & Coatings

### Rotary Applications – Mating Surface

### Turcon® / Zurcon® Slipper Seals

| Chrome plating, Anodized Surfaces, Bare Metals (hardened) and others (Non-HVOF) | | |
|---|---|---|
| Parameter | Standard Mating Surface Finish | |
| | Inch (µin) | Metric (µm) |
| $R_a$ | 2 - 8 | 0.05 - 0.20 |
| $R_t$ ($R_{max}$) | 24 - 98 | 0.63 - 2.50 |
| $R_z$ ($R_{tm}$) | 16 - 63 | 0.40 - 1.60 |
| $R_{sk}$ | -0.5 to -1.5 | |
| $T_p$ ($M_r$) | 50 - 70% @ depth of p = 0.25 $R_z$ ($R_{tm}$), reference line c = 5%$T_p$ | |

| HVOF Applied Surfaces [1)] | | |
|---|---|---|
| Parameter | Standard Mating Surface Finish | |
| | Inch (µin) | Metric (µm) |
| $R_a$ | 4 - 8 | 0.10 - 0.20 |
| $R_z$ ($R_{tm}$) | 39 - 157 | 1.00 - 4.00 |
| $R_{sk}$ | -0.1 to -3.0 | |
| $T_p$ ($M_r$) | 50 - 90% @ depth of p = 0.25 $R_z$ ($R_{tm}$), reference line c = 5%$T_p$ | |

### Groove Surfaces all Materials[2)]

| Parameter | Surface Finish Max. | |
|---|---|---|
| $R_a$ | 63 µin | 1.6 µm |

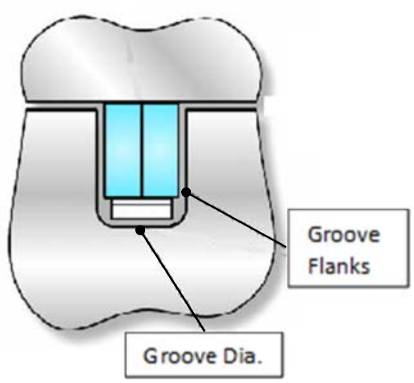
### Shaft Lay[3)]

| Parameter | Recommendation |
|---|---|
| Lead Angle RH or LH | 0.00° ± 0.05° |

### Turcon® Piston Rings

### Groove Surfaces

| Surface Finish Max. | | | | |
|---|---|---|---|---|
| Parameter | Groove Dia. | | Groove Flanks | |
| | Inch (µin) | Metric (µm) | Inch (µin) | Metric (µm) |
| $R_a$ | 32 | 0.80 | 12 | 0.31 |



# Surface Finish Recommendations & Coatings

## Static Applications – Mating Surfaces

### Elastomer Seals

| Mating Surfaces Max. 4) | | | | |
|---|---|---|---|---|
| Parameter | Constant Pressure | | Pulsating Pressure | |
| | Inch (µin) | Metric (µm) | Inch (µin) | Metric (µm) |
| $R_a$ | 60 | 1.6 | 60 | 1.6 |
| $R_z$ ($R_{tm}$) | 250 | 6.3 | 250 | 6.3 |
| $R_t$ ($R_{max}$) | 400 | 10 | 250 | 6.3 |
| Groove Diameter and Flanks Max. 4) | | | | |
| Parameter | Constant Pressure | | Pulsating Pressure | |
| | Inch (µin) | Metric (µm) | Inch (µin) | Metric (µm) |
| $R_a$ | 60 | 1.6 | 60 | 1.6 |
| $R_z$ ($R_{tm}$) | 250 | 6.3 | 250 | 6.3 |
| $R_t$ ($R_{max}$) | 630 | 16 | 400 | 10 |

1) Applies to coatings using High Velocity Oxygen Fuel (HVOF) or any other thermal spray process that creates a hard and dense surface
2) Groove surface finish recommendations follow AS568/ISO3601-2 standards
3) For rotary motion shaft surface finish must have no machining leads and be free from scratches, nicks or defects
4) Information based on O-Ring applications and should be used as a guidance only which cover the majority of sealing applications.

### Mating Surface Preparation

Slipper seals run well against un-plated surfaces at moderate speeds and pressures. In high speed and pressure reciprocating applications, harder surfaces are recommended. This is because a seal will polish its mating surface, especially softer metals during the run-in period. The run-in period is the initial time frame of high wear and friction. Once the peaks on the mating surface are broken off and the hardware and seal reach an equilibrium state then the run-in period ends.

For example, after the run-in period a reciprocating rod of stainless steel with a hardness of 28 to 30 Rockwell C and a 25µin / 0.635µm $R_a$ surface will typically be polished by the seal to 12µin / 0.30µm $R_a$, or better.

Seal friction and wear will decrease accordingly after the run-in period. Therefore, it is important to reduce the run-in period by precisely controlling the surface profile, especially on harder mating surfaces.

# Surface Finish Recommendations & Coatings

### Mating Surface Preparation

In applications where the mating surface is plated or coated, the hardware material is still considered critical. If the plating is supported by a soft substrate, then it may crack or carve-in under a high pressure load (Figure 9) due to insufficient support. The plating could also crack if it does not meet the suggested thickness. Proper hardening of the substrate material (Figure 10) along with proper coating thickness, will ensure the dynamic running surface is not damaged.

The images below are examples of poor and properly prepared hardware for a rotary seal application.

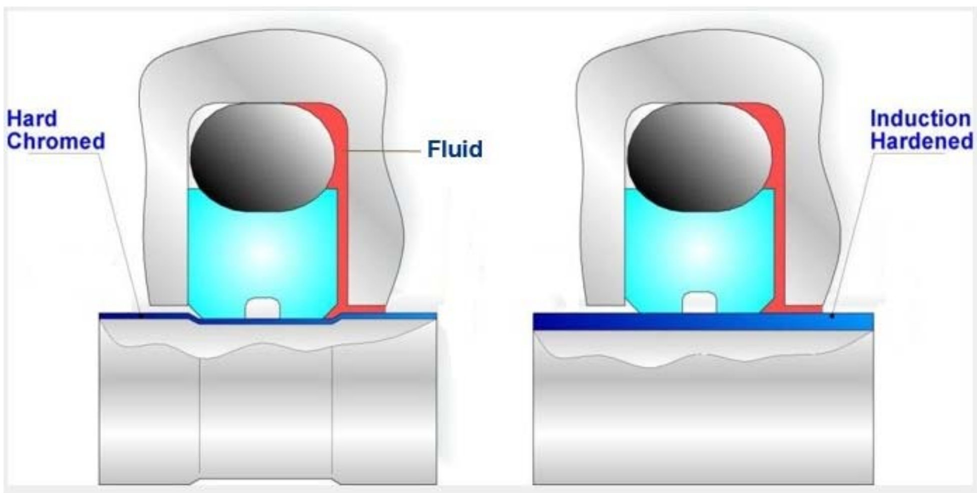



**Figure 9. Lack of substrate support** **Figure 10. Proper support**

In hydraulic applications for optimum performance, Trelleborg Sealing Solutions recommends a rod of chrome-plated steel that meets the requirements below.

| Optimum Mating Surface for Linear Hydraulic Applications | | |
|---|---|---|
| Parameters | Inch | Metric |
| Material | 42CrMo4V, purity class K3 to DIN 50602 | |
| Induction Hardened | min. HRC 45 | |
| Hardening Depth | min. 0.1" | min. 2.5 mm |
| Finishing Method | Ground and hard chrome plated, coating thickness 0.0008 to 0.0012", polished | Ground and hard chrome plated, coating thickness 20 to 30 μm, polished |

# Surface Finish Recommendations & Coatings

## Mating material – Typical materials

| Material | | Typical Hardness, Rc | | Applications |
|---|---|---|---|---|
| | | Annealed | Hardened | |
| Stainless Steel | 15-5 PH | 35 | 46 | General purpose high strength, good corrosion resistance and mechanical properties with moderate hardness. Good for use in moderate wear applications. |
| | 17-4 PH | 35 | 44 | General-purpose with moderate corrosion resistance. Material can be hardened for moderate wear applications. |
| | Type 303 | - | 20[1)] | Free machining and very soft with moderate corrosion resistance for use at low speeds and pressures. |
| | Type 304 | - | 28[1)] | Soft material with moderate corrosion resistance for use at low speeds and pressures. |
| | Type 316 | - | 28[1)] | Soft material with excellent corrosion resistance for use at low speeds and pressures. |
| | Type 440C | 22 | 44 | Heat treated material is hardest of all stainless steels, but has lower corrosion resistance than 300 series stainless steel. For use at higher speeds and pressures. |
| Carbon Steel | SAE 1045 | 19 | 58 | Good mechanical properties with higher strength than other low carbon steels. Use in non-corrosive media only. |
| Alloy Steel | 4140 | 13 | 50 | General purpose applications in non-corrosive media. For use at moderate speeds and pressures. |
| | 4340 | 13 | 50 | General service with better mechanical properties than Alloy 4140. |
| Tool Steel | D-2 | - | 62 | High hardness and wear resistance but limited corrosion resistance. For use at high speeds and moderate pressures. |
| Other Metals | Hard Anodized Aluminum 6061-T6 | - | 70+ | Hard anodized aluminum makes an excellent low friction bore surface for reciprocating piston-seal applications. Not recommended for rotary services. |
| | Bronze | 40 Rockwell B | 85 Rockwell B | For light duty service in slow speeds with low pressures and where friction and corrosion are not concerns. |
| | Mild Steel | 150 Brinell | - | Light duty service in non-corrosive media only. |
| | Titanium | 36 Rockwell C | - | Hard material with high corrosion resistance. Good for use at high pressure and speed. |
| Non-Metallic | Ceramic | 70 | | For high wear resistance at high pressures or high speeds and for low friction against Turcon® seals. |
| | Sapphire | 9 Mohs Scale | | Very hard, chemically-inert material with ability to obtain flame-polished finishes less than 1 µin. $R_a$ / 0.025 µm $R_a$. |

# Surface Finish Recommendations & Coatings

## Coating or Plating Type

| Type | | Military Specification | Hardness Rockwell C | Suggested Thickness | Corrosion Resistance | Abrasiveness to Seal | Comments |
|---|---|---|---|---|---|---|---|
| Chrome Plating | Hard Chrome | QQC 320B Class 2E | 65 | 0.0008/0.0050” (0.020/0.127mm) | Fair to Good | High | Wear resistant for light duty. Not recommended for fast rotary or corrosive applications. |
| | Thin Dense Chrome | AMS 2438 | 70 | 0.0002/0.0006” (0.005/0.015mm) | Excellent | Low | Higher wear resistance and lower friction than conventional chrome in light to moderate speeds. |
| Electroless Nickel Plating | Nickel as Deposited | MIL-C-26074B | 48-52 | 0.0010” min (0.0254mm min.) | Excellent | Low | Excellent for corrosive applications in light to moderate speeds and pressures. |
| | Nickel Fully Hardened | MIL-C-26074B | 58-70 | 0.0010” min (0.0254mm min.) | Good | High | Harder but more abrasive than deposited nickel. Not recommended for high-speed rotary. |
| Plasma Spray Coating | Chromium Oxide | See note 2. | 71 | 0.0050/0.0300” (0.127/0.762mm) | Excellent | Low | Recommended when wear life is the primary concern. Not recommended for high-shock loads. |
| | Aluminum Oxide | MIL-P-83348[3)] AMS 2448 | 60-69 | 0.0050/0.0300” (0.127/0.762mm) | Excellent | Low | Lower cost, less wear resistant but greater ductility than chromium- oxide coatings. |
| HVOF [2)] | Tungsten Carbide | MIL-P-83348[3)] AMS 2448 | 67-74 | 0.0050/0.0300” (0.127/0.762mm) | Excellent | High | High wear- resistance, with higher bonding strength, for high speed and pressure combinations. |
| Anodizing | Hard Anodized Aluminum | MIL-A-8625C Type III | Over 70 | 0.0005/0.0045” (0.013/0.114mm) | Excellent | Low | Excellent bore material in piston seal applications, as a low friction mating surface. |
| Thermal spray | Triballoy 400 & 800 | - | 55 | 0.001/0.020” (0.025/0.508 mm) | Excellent | High | Hard to get better than a 14 $R_a$ so not recommended for most dynamic seal applications. |
| Nitriding | Titanium Nitride (TiN) | - | Up to 70 | 0.000039/0.000197” (0.001/0.005mm) | Excellent | High | Wear resistance, low friction, resists corrosion. Thickness of coating can be a problem relating to useful wear life. |

1) Series 300 stainless steel is not hardened by heat treatment. Values shown are for 30% cold worked material.
2) HVOF = High Velocity Oxygen Fuel; a coating system using high-pressure, high-temperature, high velocity spray guns to improve coating density, hardness, and bond strength.
3) The military specification is noted for reference only. Plasma-spray and HVOF coatings are typically produced using industry standards developed by certain companies whose standards normally meet or exceed the military specification.

# Surface Finish Recommendations & Coatings

## Methods of Finishing

Each method used to obtain a specific surface finish such as turning, grinding, honing, polishing or superfinishing, produces a pattern or lay on the surface. This pattern in Figure 11, also known as lead, can impact sealing performance especially in rotary applications by creating the formation of leak paths. Plunge grinding is recommended for the finishing process. Lead must be removed prior to coating as well.

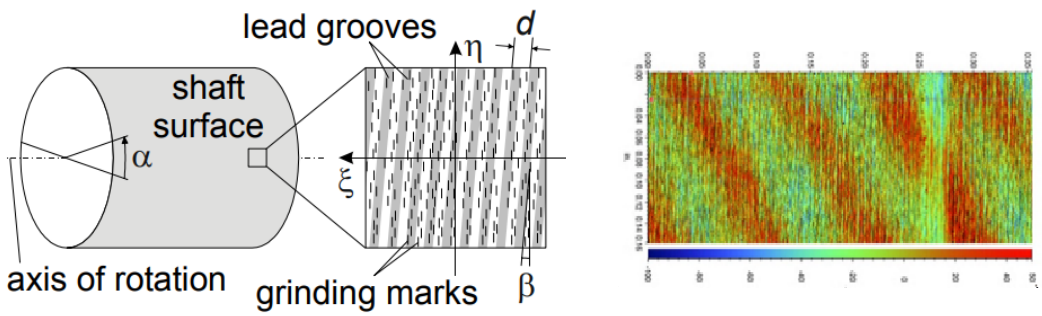



**Figure 11. Illustrations of shaft lead**

The most common method for finishing is grinding and polishing. Recommended machining methods to obtain the required surface finish can be found in the table below.

| Required surface finish $R_a$ µin (µmm) | Machining methods for metals over 40 RC and ceramics | Cold work methods for softer metals | Applications |
|---|---|---|---|
| 16<br>(0.4) | - Fine cylindrical grind<br>- Very smooth ream<br>- Fine surface grind<br>- Smooth emery buff<br>- Coarse hone<br>- Coarse lap | - Ballizing<br>- Bearingizing<br>- Roller burnish | Light duty<br>(friction and wear are not major considerations) |
| 8<br>(0.2) | - Micro-honing<br>- Honing<br>- Lapping<br>- Buffing<br>- Fine polishing<br>- Micro-grinding | - Ballizing<br>- Bearingizing<br>- Roller Burnish<br>(but initial surface must be better than 30 µin) | Requires longer wear life and/or lower friction |
| < 5<br>(<0.125) | - Lapping<br>- Super-finishing<br>- Very fine buffing<br>- Bright polishing | - Ballizing<br>- Bearingizing<br>- Roller burnish<br>(soft metals not recommended when long life is required) | Requires longer wear life and/or lower friction |

# Surface Finish Recommendations & Coatings

**Conclusion**

Surface finish is key to a durable, leak-free sealing system. The information included in this bulletin is intended to be used as a general guide.

Trelleborg Sealing Solutions Fort Wayne Product Engineering has put together a comprehensive guide using information from various Trelleborg Sealing Solution publications and through past experience as they relate to Fort Wayne products. For guidance on specific products, surface finish recommendations should be followed as outline in their respective catalog or technical bulletin.

There are several ways to finish a surface as suggested throughout this bulletin. It is recommended that customers investigate and choose the best method suited for their application and capabilities.

# Surface Finish Recommendations & Coatings

## Revision List

| | |
|---|---|
| From revision B to C | Additional topics and illustrations added<br>New format |