BAL SEAL® USER'S GUIDE

Factors That Influence
Bal Seal PTFE Seal Performance

Technical Report
TR-78 (Rev. E; 10-23-01)
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BAL SEAL ENGINEERING

19650 Pauling
Foothill Ranch, CA 92610-2610
Tel (949) 460-2100
Fax (949) 460-2300
Email: sales@balseal.com
www.balseal.com

Bal Seal Engineering Europe B.V.
Jollemanhof 16, 5th Floor
1019 GW Amsterdam
The Netherlands
Tel +31 20 638 6523
Fax +31 20 625 6018
Email: ordersbv@balseal.nl

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Bal Seal Engineering Co, Inc. ● Foothill Ranch, CA USA 92610-2610 ● Tel: 949 460-2100; Fax: 949 460-2300 ● Email: sales@balseal.com ● Web: www.balseal.com
Bal Seal Engineering Europe, B.V. ● Amsterdam, The Netherlands ● Tel: +31 20 638 6523, Fax: +31 20 625 6018 ● Email: info@balseal.nl ● Web: www.balseal.nl

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Bal Seal Engineering Europe, B.V. ● Amsterdam, The Netherlands ● Tel: +31 20 638 6523, Fax: +31 20 625 6018 ● Email: info@balseal.nl ● Web: www.balseal.nl

1.0 INTRODUCTION

Bal Seal Engineering Company is committed to conducting thorough research of our products and sealing technologies which influence the performance of BAL™ Seal PTFE seals. This commitment helps us develop a diverse line of quality PTFE sealing devices that meet the high-quality criteria required by today's seal user. We believe that it is vitally important that the users of our seals have a thorough and complete understanding of the service conditions that affect BAL Seal PTFE seal performance so that you may can obtain the highest level of performance.

This report contains the abbreviated results of literally thousands of tests performed at Bal Seal Engineering on our products. Wide ranging topics which affect seal service, such as pressure, temperature, surface speed, sealed media, piston and bore materials, coatings, PV limits, surface finishes, jacket materials, and lubrication that have been tested and analyzed are discussed here. For further information about any item concerning the performance of BAL Seal PTFE seals or about general sealing technology, contact the Bal Seal Engineering technical staff. We will be happy to answer any questions or forward you one of our many technical reports dealing with specific topics of interest.

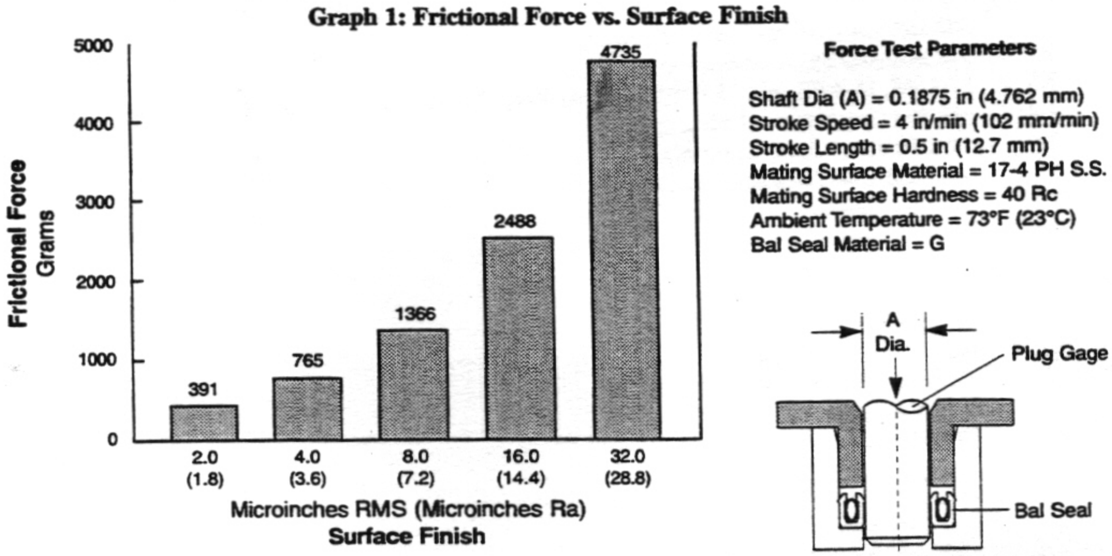
2.0 SURFACE FINISH

The performance of spring-energized BAL Seal PTFE seals is governed to a great extent by the finish of the mating surface over which the seal slides. The surface finish has a significant effect on friction, wear and sealing ability. Detailed reports on surface finish include: TR-4, "The Influence of Surface Finish on BAL Seal Performance;" TR-29, "Methods of Obtaining Surface Finishes;" and TR-51, "Measuring Surface Finishes."

2.1 Influence of surface finish on friction

In general, PTFE seal wear is proportional to frictional force; lower friction results in reduced wear. Test results indicate that improving surface finish may reduce friction. See Graph 1.

Graph 1: Frictional Force vs. Surface Finish



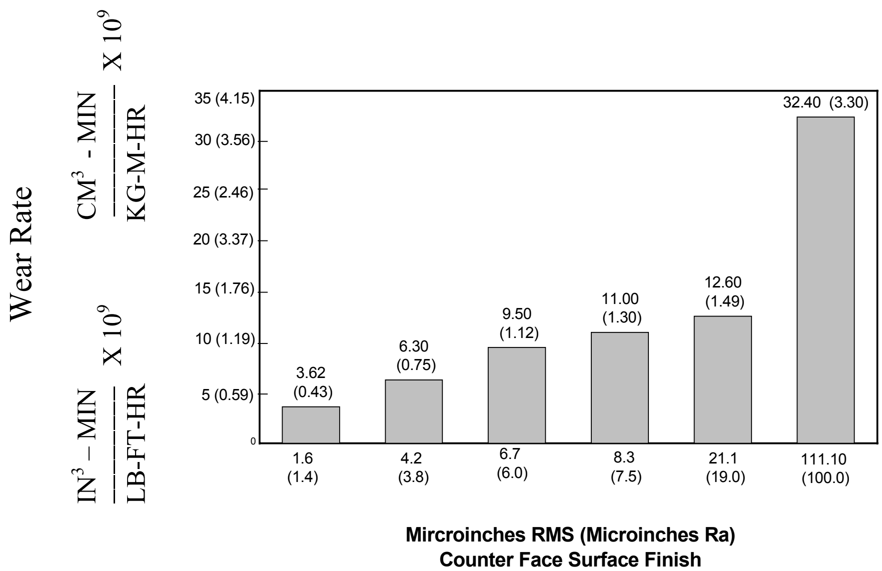
2.2 Influence of surface finish on BAL™ Seal wear

The finish of the mating surface influences the abrasive wear to which the seal is subjected. Abrasive wear occurs when a rough, hard surface slides over a softer surface. Wear occurs in the form of plastic chips cut from the surface of the seal. Test results indicate that smoother surfaces produce lower wear rates by reducing abrasive wear. See Graph 2.

Graph 2: Wear rate of BAL™ Seal GFPA material vs. various surface finishes

Wear Test

Surface Speed	=	55 fpm (17 m/min)
Loading Stress	=	55 lb/in^2 (4 Bar)
Wear Rate in Air	=	@ PV 3025 lb/in^2 x ft/min (7.5 N/mm x m/min)
Mating Surface Hardness	=	Rc 42
Mating Surface Material	=	17-4 PH Stainless Steel
Mating Surface Finish	=	1.6 to 111.1 microinches RMS (1.4 to 100
Ambient Temperature	=	microinches Ra)
Ambient Relative Humidity	=	70ºF (21ºC)
Duration	=	75% RH
BAL Seal Material	=	5 hours GFPA



2.3 Surface finish and sealing ability

Although many factors affect leakage, the sealing ability of a PTFE seal is generally proportional to fluid viscosity. Media with reduced viscosities (i.e. gases versus liquids) are more difficult to seal. This can be compensated for, to some extent, by improving the finish of the mating surface. A smoother finish creates greater sealing contact between the seal and mating surface, thus improving sealing ability. See Table 1.

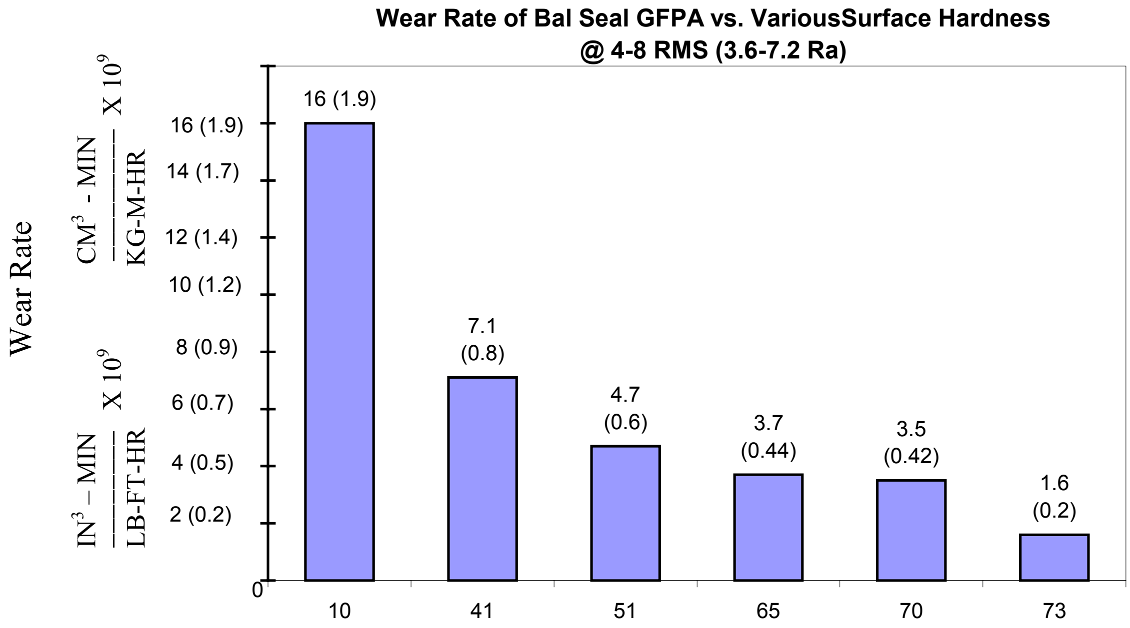
Table 1: Suggested Surface Finishes

Medium	Dynamic Surface	Static Service
Gases and Liquids At Cryogenic Temperatures	2 to 4 Microinches RMS (1.8 to 3.6 Microinches Ra)	4 to 8 Microinches RMS (3.6 to 7.2 Microinches Ra)
Gases (Air, N_2, O_2, etc.)	6 to 12 Microinches RMS (5.4 to 10.8 Microinches Ra)	12 to 32 Microinches RMS (10.8 to 28.8 Microinches Ra)
Liquids (Hydraulic Fluid, Water, etc.)	8 to 16 Microinches RMS (7.2 to 14.4 Microinches Ra)	16 to 32 Microinches RMS (14.4 to 28.8 Microinches Ra)

3.0 SURFACE HARDNESS

The hardness of the surface in contact with a BAL Seal PTFE seal has a significant effect on seal wear. Adhesion is lower between a soft PTFE seal and a hard mating surface, resulting in reduced friction. Test results indicate that harder surfaces promote less wear. See Graph 3.

Refer to TR-30, "Wear Rate of BAL Seal GFP Materials vs. Various Coatings," for complete details.



Surface Hardness (Rockwell Scale)
Graph 3

4.0 SEALING JACKET MATERIAL

The selection of the seal material should be based on a variety of considerations including the sealed media, friction requirements, pressure and velocity, wear life requirements, operating temperature, cost, lubrication, and other factors. Request report TR-8A for a complete description of the physical and mechanical properties of many BAL Seal materials.

4.1 Estimated PV limit

The PV limit is the medium value representing the product of pressure and velocity, lb/in^2 x fpm or N/mm^2 x m/min. The PV limit is extremely important in selecting the proper BAL Seal material to obtain maximum reliability and performance based on fluid medium. The PV limit of the seal material will be furnished with a design proposal.

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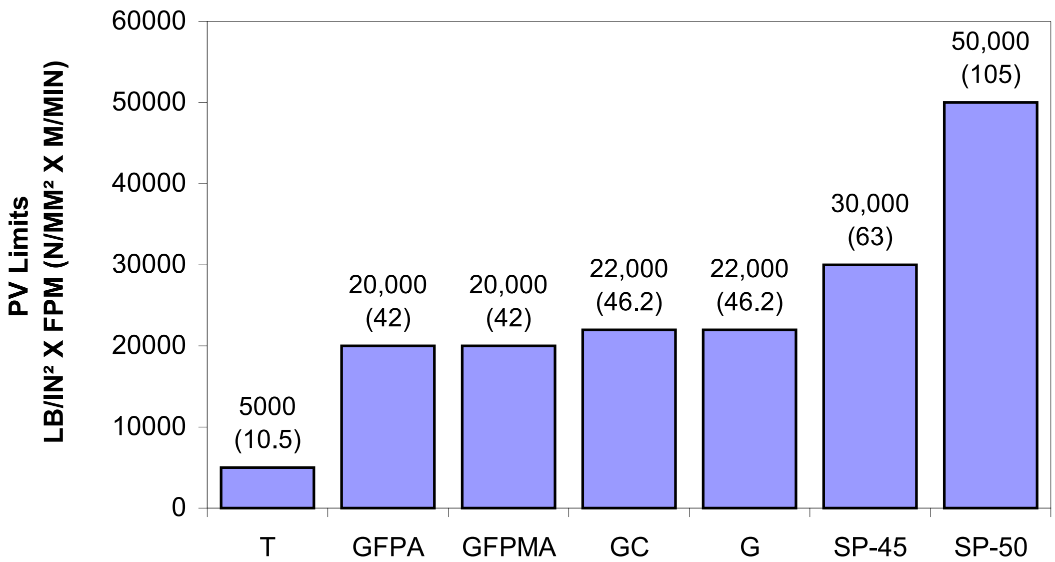
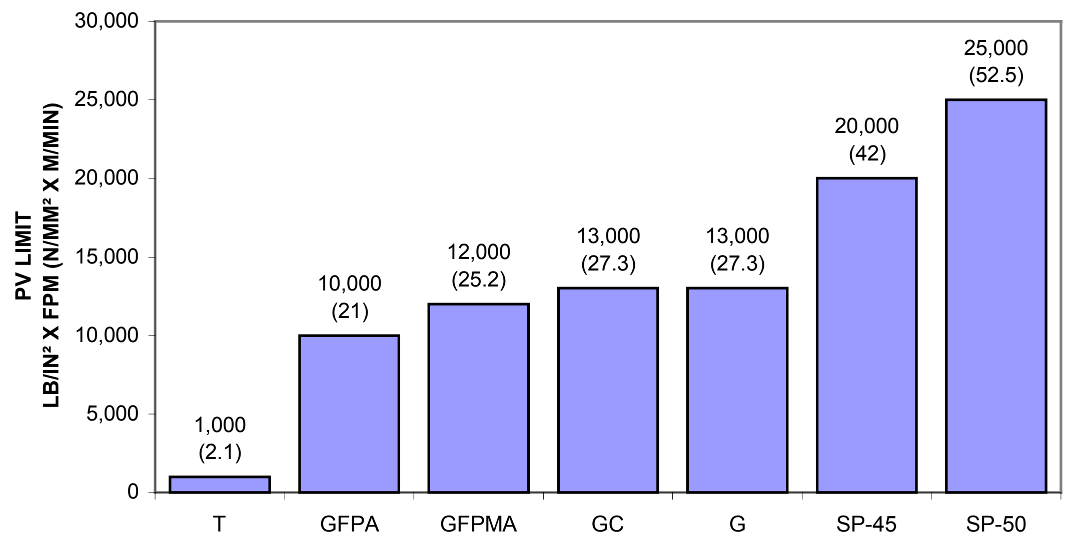
**PV Limits of Various Bal Seal Materials
in Air at 170 fpm (52 m/min) and 70°F (21°C)
Air at 75% relative humidity**



Graph 4A: Bal Seal Materials

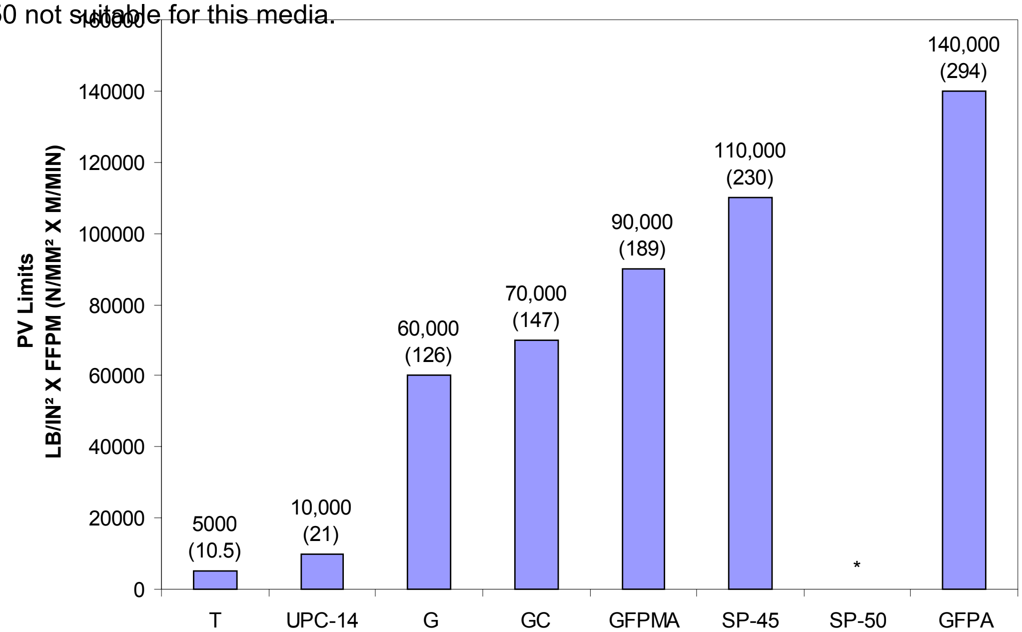
**PV Limits of Various Bal Seal Materials
In Air at 900 fpm (274 m/min) and 70°F (21°C)
Air at 75% relative humidity**



Graph 4B: Bal Seal Materials

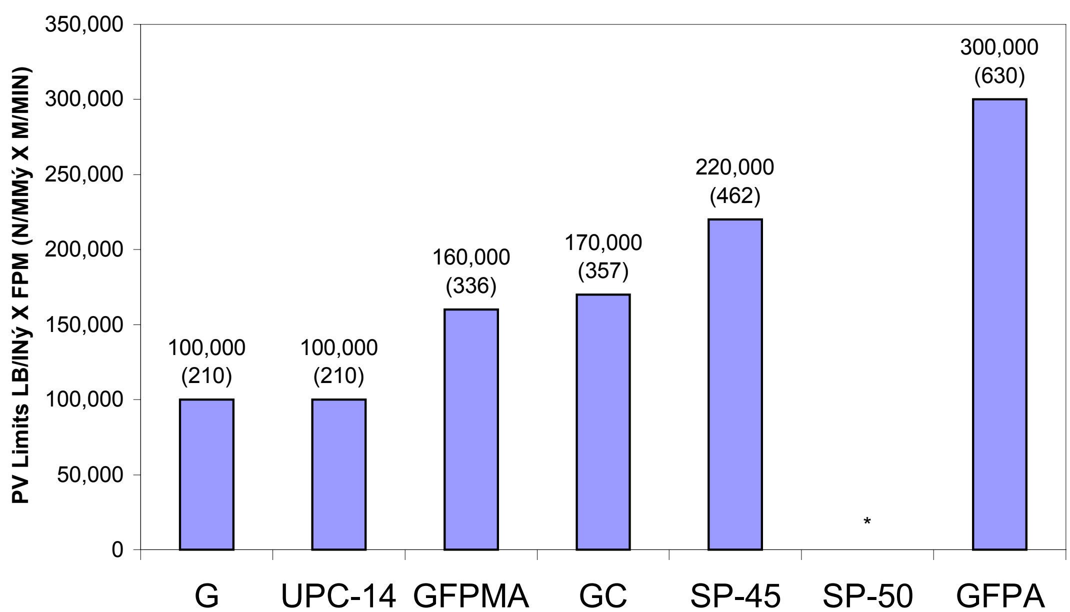
PV Limits of Various Bal Seal Materials
In Water at 170 fpm (52 m/min) and 70°F (21°C)

*SP-50 not suitable for this media.



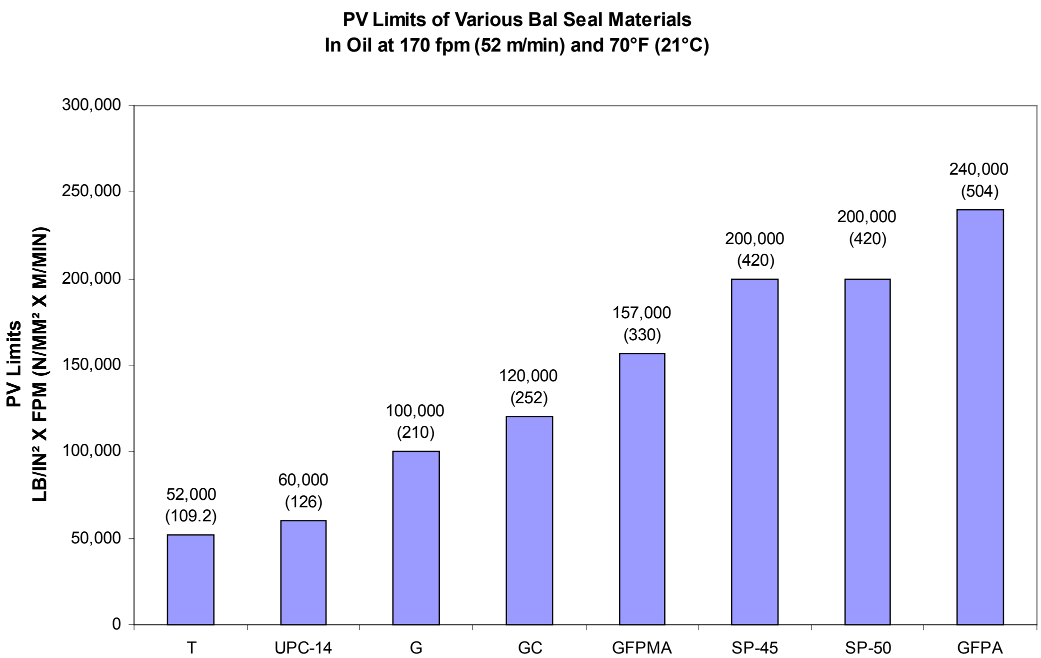
Graph 4C: Bal Seal Materials

PV Limits of Various Bal Seal Materials
in Water at 900 fpm (274 m/min) and 70°F (21°C)

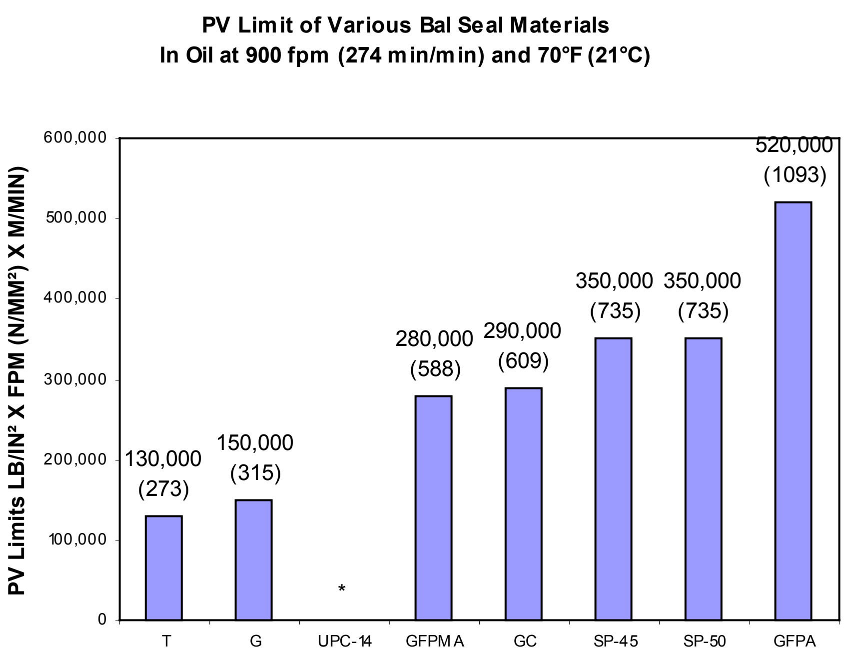


Graph 4D: Bal Seal Materials

*SP-50 not suitable for this media.



Graph 4E: Bal Seal Materials

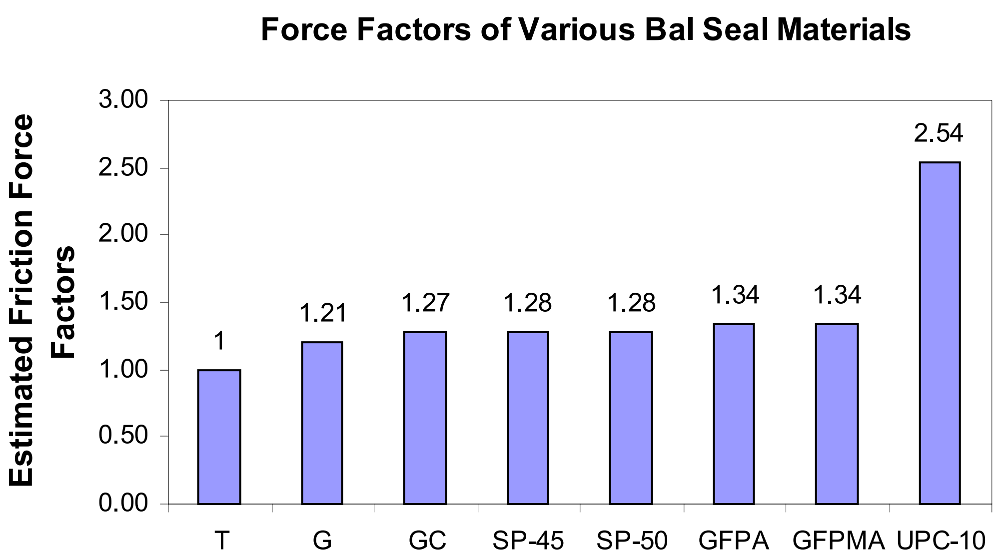


Graph 4F: Bal Seal Materials

*UPC-14 not suitable for these conditions

4.2 Influence of jacket material on friction

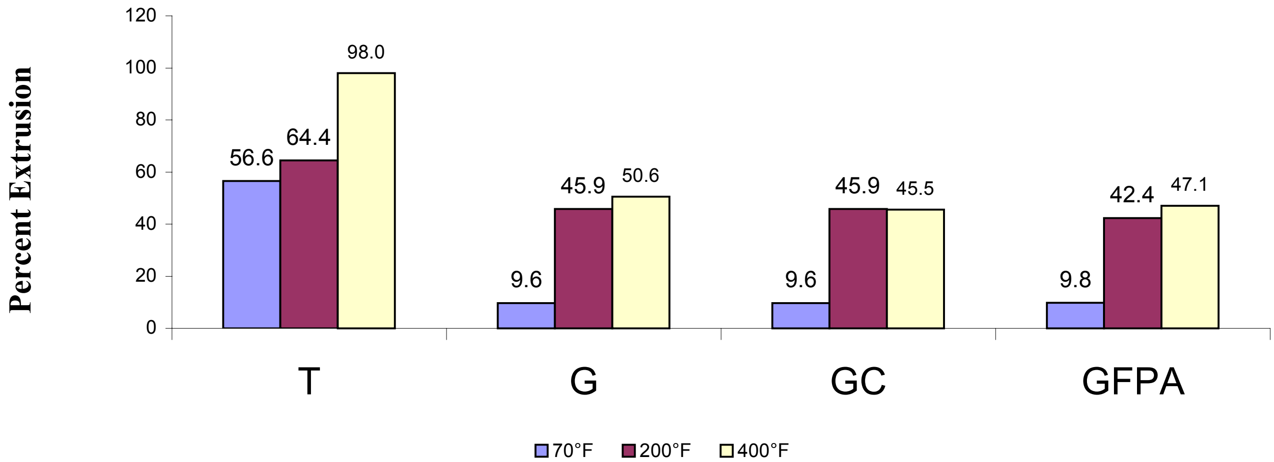
The friction produced by a seal sliding against a counter surface is influenced by a variety of factors, including jacket material. A relative comparison of the friction produced by various BAL Seal materials is shown in Graph 5. For example, the force produced by a seal made from UPC-10 was more than 2 ½ times greater than the force produced by a comparable BAL Seal made from virgin PTFE when tested under the same conditions.



Graph 5: Sealing Jacket Material

4.3 Effect of temperature on sealing jacket materials

The operating temperature of the system has a very significant effect on the physical properties of the seal material. The properties affected include extrusion resistance; wear resistance, tensile strength, elongation, and others. As the temperature in the seal area increases, the properties decline. Significant changes in material properties occur soon after the temperature rises beyond room temperature (70°F) (21°C). The increase accelerates rapidly as the temperature approaches the temperature limit of the materials (550°F for PTFE based materials). Graph 6 below shows how temperature affects the extrusion resistance of some BAL Seal materials.



Graph 6

4.4 Description of BAL™ Seal materials

4.4.1 T—virgin PTFE

General-purpose material used where or when low friction and chemical compatibility are important. It is limited to light duty service and can be used in vacuum and inert gases. BAL Seal T PTFE is subject to cold flow and exhibits high wear in water/aqueous media. BAL Seal T PTFE is compatible with most fluids and gases, except molten sodium, etc. Excellent retention at cryogenic temperatures.

4.4.2 G—graphite-filled PTFE

General purpose material used when more extrusion/creep resistance and less wear than PTFE are desired. BAL Seal G material is compatible with most fluids and gases, except strong oxidizers and certain concentrated acids. Not for general use in vacuum or dry gases.

4.4.3 GC—graphite-carbon-filled PTFE

General purpose material used when extrusion/creep resistance is important, while sealing ability and friction are secondary. Resists deformation at high temperatures. Not for general use in vacuum or inert gases.

4.4.4 SP-45—polymer-filled PTFE

Low abrasion to mating parts. General purpose material for use in contact with shaft/housing made from 300 series stainless steel, aluminum and other soft metallic or plastic materials. Suitable for sealing most liquid media including moisture, air at high speed-low pressure with very high PV values. FDA compatible.

4.4.5 SP-50—polymer-filled PTFE

Low abrasion to mating parts. General purpose material for use in vacuum, air, and inert gases in contact with soft materials like 300 series stainless steel, aluminum, and other soft metallic and plastic materials. Ideally suited for high speed-low pressure at very high PV value. FDA compatible.

4.4.6 GFPA—graphite-reinforced PTFE

Excellent wear resistant material for higher temperatures, pressures and speeds. Excellent performance in water and other aqueous solutions. Can be used in continuous duty at high pressure with adequate backing. Very high PV limit. Limited use in vacuum or inert gases.

4.4.7 GFPMA—molydisulfide-fiber-filled PTFE

Vacuum/inert gas usage, excellent wear resistance with properties similar to GFPA. High extrusion resistance.

4.4.8 UPC-10—polyethylene-based

Excellent material for use in water/aqueous media and very low temperatures. Excellent wear and extrusion resistance. Moderate friction. Suitable for scraping applications. Limited to temperatures to 170°F (75C).

5.0 OPERATING CONDITIONS

5.1 Surface speed

Dynamic friction generally increases as the surface speed becomes greater. This causes high temperature at the sealing interface, which may result in greater seal wear. The surface speed should be as low as possible to reduce frictional heat and lower the PV. Select a BAL Seal material with a high PV limit (Pressure x Velocity) for high surface speeds.

5.2 Pressure

As pressure increases, the force pressing the seal against the mating surface increases. This results in greater friction, which may increase seal wear. The system pressure should be kept at the lowest possible level to reduce the PV and obtain optimum seal performance. If seal friction is too great, select a BAL Seal material with a lower frictional force factor.

5.3 Fluid media

Liquids around the seal remove heat from the sealing interface and reduce temperature. Reducing interface temperature improves seal performance. Some liquids also provide a lubricating film, which tends to reduce friction and improve seal performance.

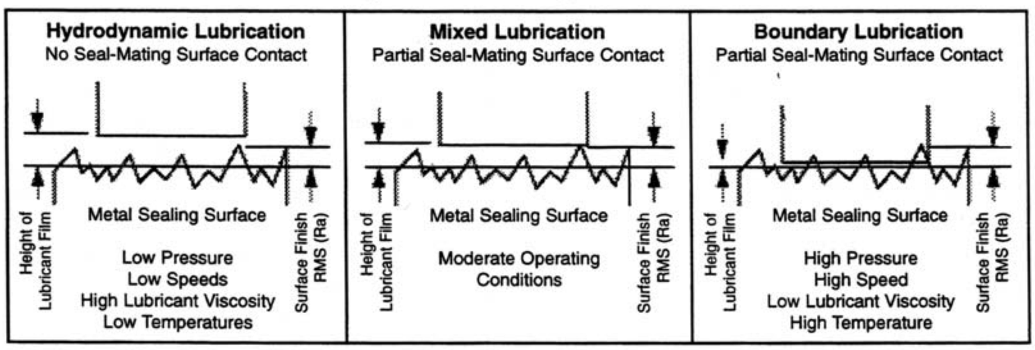
6.0 LUBRICATION

The surface finish should vary depending on the lubricating conditions present. When the lubricating film is thick, as it is during hydrodynamic lubrication, the surface finish may be rougher because the seal does not come into contact with the mating surface. When the film is thin, as it is during boundary lubrication, the finish of the mating surface should be smoother due to the greater area of contact between the seal and mating surface.

6.1 Wet lubrication

The friction and wear behavior of a BAL Seal PTFE seal in a lubricated environment is dependent upon the extent of the lubricating film separating the seal from the mating surface. One of the three types of lubricating conditions may be present in any application. See figure 1.

Figure 1: Lubricating Conditions



6.2 Dry lubrication

Dry lubricants should only be used when wet lubricants cannot be used. Dry lubricants are used to reduce friction by minimizing adhesion between the seal and mating surfaces. They provide a film that reduces the shearing action that occurs between two moving surfaces. There are three basic types of dry lubrication that are generally compatible with BAL Seal PTE seals: graphite, for most general purpose applications; molybdenum disulfide, for use in vacuum or with gas; and PTFE, for applications requiring excellent chemical compatibility and very low friction.

7.0. MATING SURFACE SELECTION

Some of the piston/shaft and bore materials typically coming into contact with BAL Seal PTFE seals are discussed here with some of their various applications.

7.1 302 and 304 stainless steels (annealed)

Moderate service conditions; good chemical compatibility; high rate of seal wear; Rc 20 to 30 annealed.

7.2 316 stainless steel (annealed)

Moderate service conditions; excellent chemical compatibility; high rate of seal wear; Rc 20 to 30 annealed.

7.3 17-4, 15-5, and 13-8 pH stainless steels (precipitation hardened)

Good chemical compatibility; moderate friction and seal wear: Rc 36 to 41 when hardened.

7.4 416 stainless steel (hardened)

Good Chemical compatibility: Rc 55 when hardened.

7.5 440c stainless steel (hardened)

Moderate corrosion resistance; low friction and seal wear; Rc 60 when hardened.

7.6 4140 and 4340 high-alloy steels

Moderate corrosion resistance; moderate friction and seal wear; Rc 50 when hardened.

7.7 Tungsten carbide

Very good resistance to wear; moderate corrosion resistance; approximately Rc 74.

7.8 Ceramics (Al_2O_3 and Cr_2O_3)

Excellent resistance to wear; very brittle; Rc 78.

8.0 MATING SURFACE COATINGS

Harder surfaces produce lower friction and lower seal wear. Some of the stainless steels, such as types 302, 304, 316, and 17-4 pH, provide good chemical compatibility by only a moderate degree of hardness. These materials are often coated with one of the following materials to provide an added degree of hardness.

8.1 Hard chrome plating

General purpose applications; hard and thick; low friction; good resistance to wear; limited corrosion resistance; Rc 65. Request report TR-14 for more information.

8.2 Dense chrome plating

More demanding applications; thin and hard, improved corrosion resistance; maintains a good surface finish; Rc 70. Request report TR-14 for more information.

8.3 Electroless nickel plating

General purpose applications; good surface finish; good resistance to wear; excellent chemical compatibility; for bores; Rc 50 as-plated; Rc 62 after heat treating. Request report TR-16 for more information.

8.4 Plasma coating

High speed applications; abrasive environments; very hard; low abrasion to seals; Rc 73. Request report TR-3 for more information.

8.5 Gas nitriding

Best overall properties; very hard and tough; requires heat treating at 1050°F (566°C); shafts or bores; Rc 70.

9.0 DESIGN CONSIDERATIONS

9.1 Radial clearance

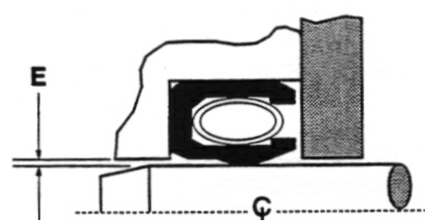
The radial clearance between the piston/shaft and bore has a significant effect on seal performance.

As system pressures and temperatures increase, the clearance must be reduced to minimize the possibility of extrusion. Some very general guidelines are indicated below. Extensive testing conducted by Bal Seal Engineering Company has led to the development of recommended clearances based on pressure, temperature, and seal diameter, seal cross section, seal material, and other factors.

A suggested radial clearance will be provided with every seal design proposal.

Figure 2 : Radial clearance between the piston/shaft and bore

Pressure		E Maximum Radial Clearance
PSI	Bar	Inch (mm)
150	10	0.0040 (0,10)
500	35	0.0040 (0,10)
1000	70	0.0035 (0,09)
3000	210	0.0030 (0,08)
At higher pressures, tighter E clearances are required		



9.2 Piston/Shaft and bore tolerances

Because BAL Seal PTFE seals re spring-energized, they have the unique ability to compensate for wide tolerances. However, optimum results may be obtained when following the recommendations indicated in Figure 3.

FIGURE 3: Piston/Shaft and Bore Tolerances

Piston/Shaft (B Diameter) Range in inches (mm)	Piston/Shaft (B Diameter) Tolerance in inches (mm)	Piston/Shaft (A Diameter) Tolerance in inches (mm)
0.000 to 0.376 (0,00 to 9,35)	+0.0000 / -0.0005 (+0,00 / -0,01)	+0.0005 / -0.0000 (+0,01 / -0,00)
0,367 to 1,500 (9,55 to 38,10)	+0.0000 / -0.0010 (+0,00 / -0,03)	+0.0010 / -0.0000 (+0,03 / -0,00)
1,501 to 2,500 (38,13 to 63,50)	+0,0000 / -0.0015 (+0,00 / -0,04)	+0.0015 / -0.0000 (+0,04 / -0,00)
2,501 to 4,000 (63,53 to 101,60)	+0.0000 / -0.0020 (+0.00 / -0,04)	+0.0020 / -0.0000 (+0,05 / -0,00)
4,001 and larger (101.63 and larger)	+0.0000 / -0.0030 (+0,00 / -0,08)	+0.0030 / -0.0000 (+0,08 / -0.00)

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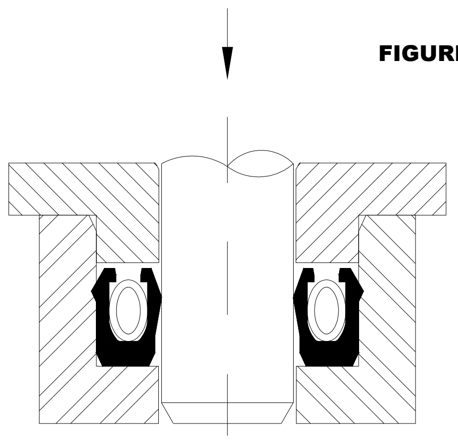
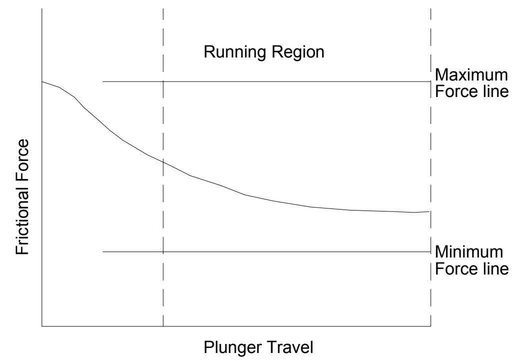
10.0 MEETING FORCE REQUIREMENTS

Superior seal performance can be obtained by taking advantage of the special quality assurance testing procedures we offer. Force testing can be implemented to maintain tighter tolerances and enhance the consistency of seal performance. The specified seal force is met by changing the loading spring. BAL Seal PTFE seals are available in various spring forces, which determine, to a great extent, the sealing ability, friction, and duration of the seal. The procedure and a typical computer printout of the frictional force of an individual seal are shown in Figure 4. Request Report TR-31 for information.

FIGURE 4: Frictional Force Testing



Method of Measuring Linear Force
View A



Force vs. Plunger Travel of Individual Seal
View B

11.0 SUMMARY

The performance of a BAL Seal PTFE seal is not dependent on just one or two operating conditions, but on a variety of factors working simultaneously. Selection of a BAL Seal PTFE seal for a particular application requires a complete understanding of these factors. At Bal Seal Engineering Company, we continuously test our materials, springs, and seals to find out how service conditions affect performance, and to discover new ways to improve seal design. We hope that by using the information contained in this report, seal users can improve the performance of their products. Please contact the Bal Seal Engineering technical staff for any additional information.

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