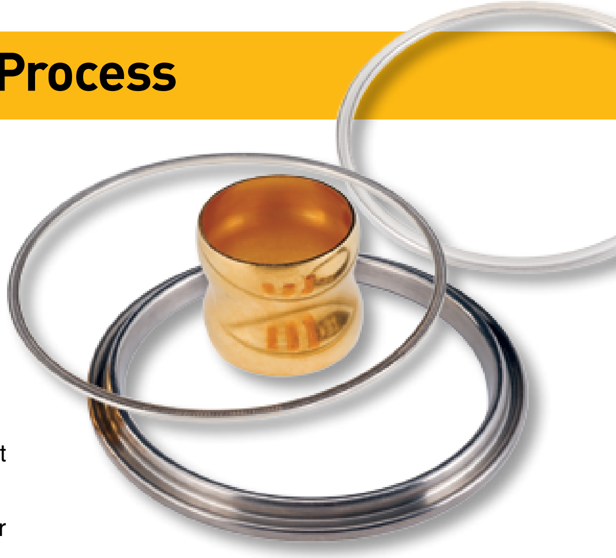
Section D – Material Selection Process



Introduction to the Material Selection Process

With the seal type, diameter and cross-section already determined, the following pages (D-52 to D-65) provide specific guidance in selecting the appropriate material(s), temper and finish.

Comprehensive data is given to ensure an optimum match between the many material choices and the application. However, we are always pleased to offer additional technical consulting and advice if required. To obtain the fastest response please send us your completed application data sheet (see page F-103, F-104), for immediate review by our product specialists and engineering staff.

Metal seal material, temper and finish are designated in the part number as shown below.

EXX - 000000 - 00 - 00 - 0 - XXX

- Metal Seal Type (Section B) → EXX
- Seal Diameter (inches specified to three decimal places – Section C) → 000000
- Seal Cross Section (Section C) → 00
- **Material Code** → 00
- **Temper Code** → 0
- **Finish Code (material & thickness)** → XXX

This section includes: **Page**

Selecting the Metal Seal Material

Metal Seal, Platings, Coatings and Finishes

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Selecting the Metal Seal Material

The tables below and opposite list all the available materials for non-spring energized seals and spring energized seals.

Starting in the column appropriate to the chosen metal seal type, make the primary material selection by choosing a "preferred", or possibly "optional" material compatible with the maximum working temperature in the application. Information on temperature resistance is given on the following pages.

Other factors that may also require consideration include 'NACE' approval (corrosion resistance) and chemical compatibility. Additional guidance on the effects of material choices on seal performance (load, springback and pressure rating) may be found on pages E-69 to E-77.

Special materials are also available to meet unusually severe operational requirements, or unique procurement specifications. Generally, these will not be stock item materials and may be subject to some additional lead time and material lot charges.

EXX - 000000 - 00 - 00 - 0 - XXX

Material Code

Non-Spring Energized Seals							
Material Code	**Material (Common Designation)**	**NACE Approved** *(See Note 3)*	**C-Ring**	**E-Ring**	**O-Ring**	**U-Ring**	**Wire Ring**
01	304 Stainless Steel				**Preferred**[1]		**Preferred**
02	316 Stainless Steel				Special		Special
03	321 Stainless Steel				**Preferred**[1]		Special
04	347 Stainless Steel				Special		Special
15	Stainless Steel Alloy A-286		Special				
16	17-4 PH Stainless Steel		Special				
06	Alloy 600				Special		
25	Alloy 625		Special				
14	Alloy 718	Yes	**Preferred**	**Preferred**	Optional[2]	**Preferred**	Special
07	Alloy X-750		Optional	Optional	Optional[2]	Optional	Special
20	Hastelloy C-276	Yes	Special				
23	Waspaloy		Optional	Optional		Optional	
29	Rene 41		Special	Special		Special	
05	Monel 400				Special		Special
39	Haynes 188		Special			Special	
09	Haynes 25		Special		Special		
08	Aluminum Alloy 1100						**Preferred**[4]
12	Copper						Special
13	Nickel						**Preferred**[4]

1: 321 Stainless Steel is standard for 0.125 inch and smaller free height metal O-rings. 304 Stainless Steel is standard for 0.156 inch and larger free height metal O-rings.
2: Alloy X-750 is optional for 0.250 inch and smaller free height metal O-rings. Alloy 718 is optional for 0.375 inch and larger free height metal O-rings.
3: Approved for use in corrosive seal service per NACE MR-01-075 specification.
4: 3/32 free height wire rings are only available in stainless steel, nickel, and nickel alloys.

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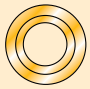
Spring Energized Seals

Material Code	Jacket/Spring Material Combination (Common Designation) Jacket/Spring	NACE Metal C-Ring Approved *(See Note 3 on previous page)*	Spring Energized Metal C-Ring 	Spring Energized Metal O-Ring 
01	304 Stainless Steel / 304 Stainless Steel		Optional	**Preferred**
02	304 Stainless Steel / Cobalt Chromium-Nickel Alloy		Special	
03	Alloy X-750 / Cobalt Chromium-Nickel Alloy		Special	
04	Aluminum Al 1100-0 / 304 Stainless Steel		Special	
05	Alloy X-750 / 304 Stainless Steel		Special	
06	Alloy X-750 / Alloy X-750		**Preferred**	Special
07	304 Stainless Steel / Alloy X-750		Optional	
08	304 Stainless Steel / Nimonic 90		Special	
09	Alloy X-750 / Nimonic 90		Special	
10	Alloy X-750 / Alloy 718		Optional	
11	Alloy 718 / Alloy 718	Yes	Optional	
12	Alloy 718 / Alloy X-750	Yes	Optional	
13	Nickel / Alloy X-750		Special	
14	Alloy 718 / Cobalt Chromium-Nickel Alloy		Special	
15	Cobalt Chromium-Nickel Alloy / Cobalt Chromium-Nickel Alloy		Special	
16	Alloy C-276 / Alloy C-276		Special	
17	Alloy 625 / Alloy 625		Special	

Other materials are available upon special request. Please contact one of our applications engineers for assistance.

Temperature Capability

Stainless Steel								
		AMS Specifications						
				Wire				
Material	UNS No.	Strip & Sheet	Tubing	Wire Rings	Spring	Description	Maximum Recommended Service Temperature	Typical Usage
304/304L	S30400	AMS 5511, AMS 5513	AMS 5560, AMS 5565	AMS 5697	AMS 5857	The most commonly used stainless steel alloy. Excellent formability and good corrosion resistance. Found in a wide variety of commercial, industrial and consumer applications.	600°F (316°C)	C-rings, O-rings and wire rings in cryogenic to moderate temperature applications requiring mild corrosion resistance.
316/316L	S31600		AMS 5597	AMS 5690		The addition of molybdenum offers improved corrosion resistance when compared to 304/304L. These alloys also offer enhanced creep, stress-to-rupture, and tensile strengths at elevated temperatures.	600°F (316°C)	
17-4PH	S17400	AMS 5604				A chromium-nickel-copper, precipitation hardenable martensitic stainless steel used for applications requiring high strength and a moderate level of corrosion resistance.	600°F (316°C)	
321	S32100		AMS 5570, AMS 5576	AMS 5689		Stabilized by the addition of titanium, this alloy provides excellent resistance to intergranular corrosion following prolonged exposure to elevated service temperatures.	800°F (427°C)	
347	S34700			AMS 5674		Stabilized by the addition of columbium and tantalum. Offers increased resistance to sensitization compared to alloy 321.	800°F (427°C)	
Alloy 286	S66286	AMS 5525				Designed for applications requiring high strength with good corrosion and oxidation resistance at moderately high temperatures. This precipitation-hardenable alloy provides a high degree of uniformity in developing maximum strength, which can be duplicated application after application.	1200°F (649°C)	C-rings in more severe environments requiring enhanced strength, corrosion and oxidation resistance.

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Selecting the Metal Seal Material

Temperature Capability

Nickel Alloys

Material	UNS No.	AMS Specifications				Description	Maximum Recommended Service Temperature	Typical Usage
				Wire				
		Strip & Sheet	Tubing	Wire Rings	Spring			
Monel® 400	N04400		AMS 4574	AMS 4730		A ductile nickel-copper solid-solutioned-strengthened alloy with good general corrosion resistance in a wide range of media. Slightly magnetic at room temperature.	600°F (316°C)	C-ring applications requiring corrosion resistance to specific environments.
Alloy 276	N10276	AMS 5530				A nickel-molybdenum-chromium alloy offering superior corrosion resistance. Excellent resistance to pitting and stress corrosion cracking. Suitable for a wide variety of chemical processing environments.	1000°F (538°C)	C-ring applications requiring the utmost in corrosion protection.
Alloy 600	N07600		AMS 5580			A nickel-chromium alloy with good oxidation resistance at moderate service temperatures. Good resistance to carburizing and chloride containing environments.	1000°F (538 °C)	C-ring applications requiring corrosion resistance to specific environments.
Alloy 625	N07625	AMS 5599				A solid-solution-strengthened, nickel-chromium-molybdenum alloy with good high-temperature strength. Offers good oxidation resistance and excellent corrosion resistance.	1000 °F (538°C)	
Nimonic® 90	N07090				AMS 5829	A nickel-chromium-cobalt alloy being precipitation hardenable, having high stress-rupture strength and creep resistance at high temperatures	1000°F (538°C)	Spring material for spring-energized C-rings.
Alloy X750	N07750	AMS 5598	AMS 5582		AMS 5699	An age-hardenable nickel-based superalloy with good high-temperature strength. Readily cold-formed using standard forming techniques.	1100°F (593°C)	These materials are useful for all seal types up to their maximum service temperature. Particularly suitable for gas turbine and aerospace applications with large thermal and mechanical transients.
Alloy 718	N07718	AMS 5596	AMS 5590			An age-hardenable nickel superalloy with excellent high-temperature strength and good oxidation resistance. Excellent cold-forming characteristics. Higher strength than Alloy X750 with improved weldability.	1200°F (649°C)	
Waspaloy	N07701	AMS 5544				An age-hardenable nickel-based superalloy with very good high-temperature strength and oxidation resistance at service temperatures up to 1350°F (732°C). Strength is superior to Alloy 718 above 1150°F.	1350°F (732°C)	
Rene 41	N07041	AMS 5545				An age-hardenable nickel-based superalloy with superior strength up to 1450°F (788°C).	1450°F (788°C)	
Haynes® 230	N06230	AMS 5878				A solid-solutioned-strengthened, nickel-chromium-tungsten-molybdenum alloy with good high-temperature strength and excellent oxidation resistance. Excellent thermal stability and resistance to nitriding environments.	1600°F (871°C)	Not as strong as the age-hardenable nickel alloys, these materials are useful where long term oxidation resistance is a prime concern.
Haynes® 214	N/A (DIN 17744-2.4646)					A nickel-chromium-aluminum-iron alloy with superior high-temperature oxidation resistance and very good high-temperature strength. Highly resistant to carburizing and nitriding environments.	1800°F (982°C)	

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Temperature Capability [cont.]

Cobalt Alloys

Material	UNS No.	AMS Specifications		Wire		Description	Maximum Recommended Service Temperature	Typical Usage
		Strip & Sheet	Tubing	Wire Rings	Spring			
Elgiloy® Cobalt-Chromium-Nickel Alloy	R30003	AMS 5876			AMS 5833	This cobalt-chromium-nickel alloy gives a combination of high strength, ductility and good mechanical properties and is age hardenable. Excellent fatigue life and corrosion resistance in numerous environments.	700°F (371°C)	Approved high strength spring material for sour gas application.
Haynes® 25	R30605	AMS 5537				A solid-solution-strengthened, cobalt-nickel-chromium-tungsten alloy with very good resistance to high-temperature oxidizing environments. Largely replaced by Haynes 188 and Haynes 230.	1600°F (871°C)	High temperature C-ring applications. High wear C-ring applications.
Haynes® 188	R30188	AMS 5608				A cobalt-nickel-chromium-tungsten alloy with very good resistance to high-temperature oxidizing environments. Better thermal stability than Haynes 25 with similar high-temperature strength.	1600°F (871°C)	High temperature C-ring applications.

Temperature Capabilities

Other Materials

Material	UNS No.	AMS Specifications		Wire		Description	Maximum Recommended Service Temperature	Typical Usage
		Strip & Sheet	Tubing	Wire Rings	Spring			
Indium	N/A					Commercially pure (> 99.9%) Indium	150°F (66°C)	Electroplated in various combinations to provide aductile outer layer that enhances seal-ability and/or corrosion. Occasionally used for wire rings.
Lead	N/A					Commercially pure (> 99.9%) Lead	400°F (204°C)	
Teflon®	N/A					Chemically inert polymer. Highly resistant to chemical attack.	500°F (260°C)	Near net-shape electroplated anti-wear coatings. Used to prolong seal life in applications with high thermal, mechanical or vibrational movement.
Copper	C11000					Commercially pure (> 99.0% copper). Fair corrosion resistance.	600°F (316°C)	Electroplated in various combinations to provide aductile outer layer that enhances seal-ability and/or corrosion. Occasionally used for wire rings.
Nickel 200	N02200					Commercially pure (> 99.9%) Nickel	600°F (316°C)	Low-temperature wire rings.
Aluminum Alloy 1100	A91100					Commercially pure (> 99.0%) aluminum. Good corrosion resistance and high formability.	1000°F (538°C)	Machined seals.
Silver	N/A					Commercially pure (> 99.9%) Silver	1200°F (650°C) Oxidizing 800°F (425°C) non-oxydizing	Electroplated in various combinations to provide aductile outer layer that enhances seal-ability and/or corrosion. Occasionally used for wire rings.
TriCom®	N/A					A cobalt-chrome-carbide anti-wear coating with a low coefficient of friction and good oxidation resistance.	1200°F (649°C)	Near net-shape electroplated anti-wear coatings. Used to prolong seal life in applications with high thermal, mechanical or vibrational movement.
Nickel 201	N02201					Low-carbon version of Nickel 200. Preferable for application temperatures above 600°F (316°C).	1400°F (760°C)	High-temperature wire rings.
Gold	N/A					Commercially pure (> 99.9%) Gold	1700°F (927°C)	Electroplated in various combinations to provide aductile outer layer that enhances seal-ability and/or corrosion. Occasionally used for wire rings.
Tribaloy® T-400	N/A					Cobalt-chromium-molybdenum alloys offering excellent wear resistance at extreme temperatures.	1800°F (982°C)	HVOF plasma-sprayed anti-wear coatings for extreme environments. May require post-coating machining to meet design tolerances.
Tribaloy® T-800	N/A						1800°F (982°C)	
Nickel	N/A					Commercially pure (> 99.9%) Nickel	2200°F (1204°C)	Electroplated in various combinations to provide aductile outer layer that enhances seal-ability and/or corrosion. Occasionally used for wire rings.

Aerospace Material Specification (AMS) Reference

Our material procurement specifications ensure that we receive only the highest quality materials in a condition best suited for seal manufacture. This ensures that you receive the highest quality seals with consistent performance. Our procurement specifications comply with (but are frequently more stringent than) the following AMS specifications.

Material (Common Designation)	Strip & Sheet	Tubing	Wire	
	C-Rings, E-Rings, U-Rings	O-Rings	Wire Rings	Springs
304 Stainless Steel	AMS 5511	AMS 5560, 5565	AMS 5697	AMS 5857
316 Stainless Steel		AMS 5584	AMS 5690	
17-4 PH Stainless Steel				
Monel 400		AMS 4574	AMS 4730	
Cobalt Chromium-Nickel Alloy	AMS 6876			AMS 5833
321 Stainless Steel		AMS 5570, 5576	AMS 5689	
347 Stainless Steel		AMS 5575	AMS 5674	
Alloy 600		AMS 5580		
Alloy 625	AMS 5599			
Aluminum Al 1100-0	AMS 4001			
Hastelloy C-276	AMS 5530			
Alloy X-750	AMS 5598	AMS 5582		AMS 5699
Alloy 718	AMS 5596	AMS 5590		
Stainless Steel Alloy A-286	AMS 5525			
Waspaloy	AMS 5544			
Rene 41	AMS 5545			
Haynes 188	AMS 5608			

Yield Strength, Relaxation & Springback

Yield strength and stress relaxation are particularly important in the design and application of resilient metal seals for elevated temperatures. For any given seal design, springback is a function of yield strength and stress relaxation (as well as modulus of elasticity).

A useful estimation of springback for short term exposure to elevated temperatures may be obtained by derating the published springback by the ratio of the yield strength at the elevated temperature to the yield strength at ambient temperature.

$$SB_A = \frac{YS_T}{YS_{RT}} SB_o$$

Where: SB_A = Springback adjusted

YS_T = Yield Strength at elevated temperature

YSR_T = Yield Strength at room temperature

SB_o = Original Springback

Stress relaxation occurs when material is exposed to long term elevated temperatures. This results in reduced load and springback.

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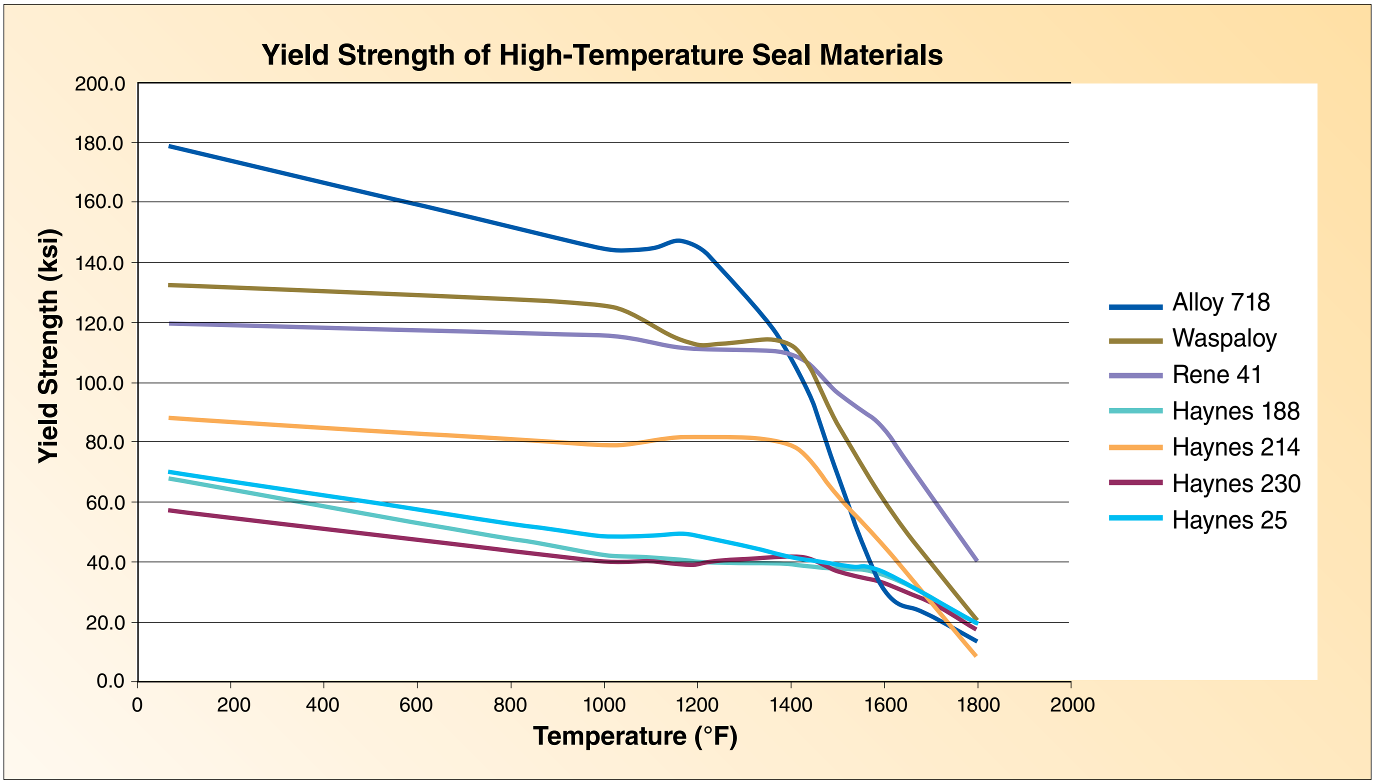
Temperature Capability – Yield Strength								
Temperature Deg. F	Alloy 718 HT'd per AMS 5596 ksi	Alloy X750 HT'd per AMS 5598 ksi	Waspaloy HT'd per AMS 5544 ksi	Rene 41 Yield ksi	Haynes 188 Yield ksi	Haynes 214 Yield ksi	Haynes 230 Yield ksi	Haynes 25 Yield ksi
70	178.4	141.1	131.8	119.0	67.3	87.6	56.9	69.0
1000	144.0	124.9	125.2	115.0	42	78.9	39.7	48.0
1100	144.4	123.1	118.6	113.0	40.9	80	39.4	48.0
1200	144.8	121.2	112.0	111.0	39.7	81.1	39.0	48.0
1400	108.6	92.0	111.8	109.0	38.9	78.8	41.2	41.0
1500	69.6	67.6	85.9	96.5	37.4	61.9	36.8	38.5
1600	30.6	43.1	60.0	84.0	35.9	45	32.4	36.0
1700	21.8	26.1	39.8	62.0	27.5	26.4	25.9	27.0
1800	13.0	9.1	19.6	40.0	19.0	7.8	17.3	18.0



Section D
Material Selection

Metal Seal Material Temper

We provide clear recommendations on the best choice of material condition for the type of seal selected and material type. For high performance resilient metal seals manufactured from nickel alloys such as X-750, 718 and Waspaloy, we recommend a solution annealed and age hardened heat treatment to our standard (-6) condition after forming. This increases springback and load by increasing yield strength, as well as improving fatigue resistance and creep resistance. Metal O-Rings and Spring Energized C-Rings are frequently manufactured from austenitic stainless steels which are not precipitation hardenable. These seals are supplied in the work hardened condition.

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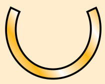
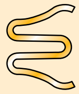
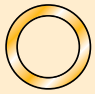
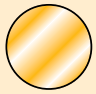
Temper Code

Temper Code	Temper Description
1	Work Hardened
2	Age Hardened
4	Annealed
6	Solution Heat Treat, (Stabilization Heat Treat if applicable), and Precipitation Heat Treat
8	Temper For Service Per NACE MR0175 Specification

Temper Codes for Non-Spring Energized Seals

Material Code	Material (Common Designation)	 C-Ring (Face Seal)	 Axial C-Ring	 E-Ring	 O-Ring	 U-Ring	 Wire Ring
01	304 Stainless Steel				1		4
02	316 Stainless Steel				1		4
03	321 Stainless Steel				1		4
04	347 Stainless Steel				1		4
05	Monel 400				1		4
06	Alloy 600				1		
07	Alloy X-750	6	1		1†		
08	Aluminum Alloy 1100						4
09	Haynes 25				1		
10	Gold						4
11	Silver						4
12	Copper						4
13	Nickel						4
14	Alloy 718	6*	1 or 6*	6*	1†	6*	
15	Stainless Steel Alloy A-286	6	1				
16	17-4 PH Stainless Steel	6	1				
20	Hastelloy C-276	1	1				
23	Waspaloy	6	6	6		6	
25	Alloy 625	6	1				
29	Rene 41	6	6	6		6	
39	Haynes 188	1	1			1	

*NACE APPROVAL – For approval in corrosive service per NACE MR-01-075 Specification, specify temper code 8.
†Alloy X-750 and 718 O-Rings are available in -6 and -2 tempers for increased fatigue and stress relaxation resistance and seating load.

Temper Codes for Spring Energized Seals

The -1 Work Hardened temper code is standard for all Spring Energized Seals. All springs are supplied in an appropriate spring temper prior to installation in the seal jacket. The -6 Solution Annealed and Age Hardened temper code is available for increased fatigue resistance of the jacket/spring combinations (at right) in cyclic operating conditions such as piston engines.

Material Code	Jacket/Spring Materials
06	Alloy X-750/Alloy X-750
11	Alloy 718/Alloy 718

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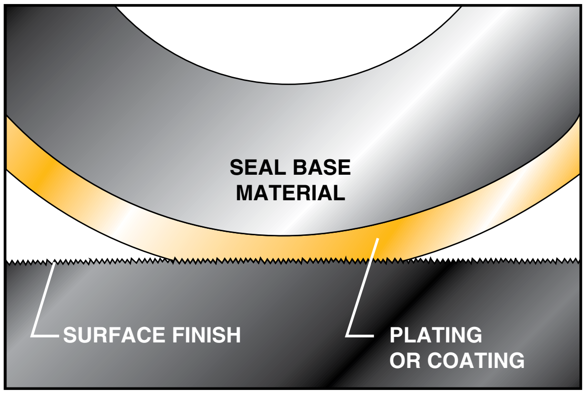

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Finish Code

Finish Thickness

Specialized platings and coatings allow us to modify the surface properties of a metal seal to create a ductile, low hardness outer surface layer. This acts as an integral "gasket" and ensures optimum sealing despite mating surface imperfections. However, unlike a large surface area traditional flat gasket, the narrow footprint of a metal seal produces a high localized contact stress without excessive bolt-up loads.

Platings and coatings can also improve seal performance by reducing the coefficient of friction of the seal and preventing galling. This assists the seal to slide and "seat down" properly during initial compression or permit, for example, limited dynamic use as a valve stem seal.

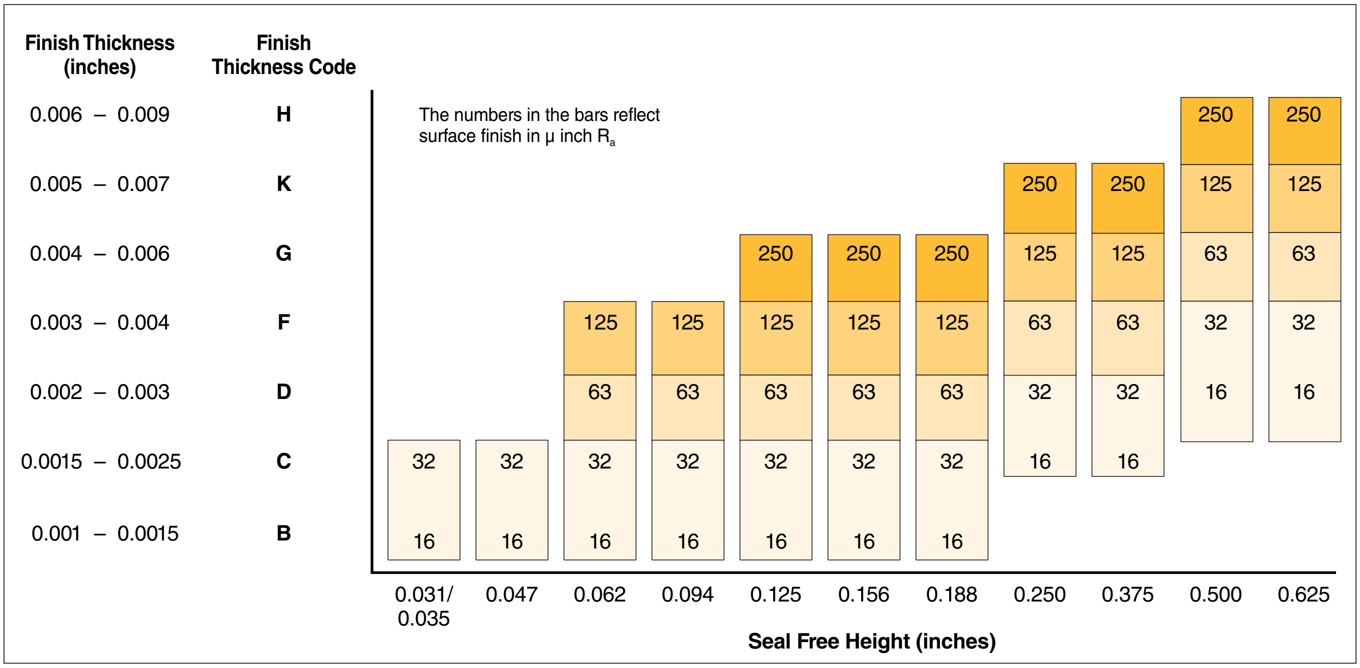
In addition to the primary physical properties of ductility and softness, seal coatings are also chosen to withstand high temperatures and often corrosive or oxidizing environments. With a wide choice of surface coatings available, we recommend the selection be made by the following process of elimination.

1. Eliminate all platings and coatings with inadequate high temperature capability (see table below).
2. Eliminate all coatings chemically incompatible with the fluid medium.
3. Choose the softest remaining coating able to withstand the seating stresses. (Ultra soft materials such as Indium and Lead are very easily damaged and subject to creep if overstressed. They should only be selected for specially critical applications with well controlled handling and installation instructions.)
4. NOTE: Silver remains, for many applications, the preferred choice.

Finish Code	Finish Material	Properties, Uses And Limitations	Maximum Temp °F	Maximum Seal Load Lb/In
	Unplated	Typically air applications where total leak tightness is not required. Lowest cost. Contact your local representative for anti-gall coating options.	depends on base	not limited
SFX (unplated) SSX (Silver) SGX (Gold) etc.	Super-Finishing	Spin-polished substrate sealing surfaces with a circular lay. Improves leakage control on unplated or low load seals, or for high vacuum.	depends on base & plating	depends on plating
IP	Indium (In)	Extremely soft metal, excellent for cryogenics, low strength flanges, optical components and vacuum. Not for use with high load seals or at high pressures, due to creep and extrusion.	150	350
LP	Lead (Pb)	Similar properties to Indium, although slightly harder and higher temperature capability. Not for use with high load seals.	400	400
PC	Tin (Sn)	Very soft metal, excellent for cryogenics, low strength flanges, optical components and vacuum. Not for use with high load seals or at high pressures, due to creep and extrusion.	400	400
TC	Teflon (PTFE)	Chemically inert soft polymer. Not for use with high load seals. Permits some permeation of gases.	450	450
SP	Silver (Ag)	Closest to an ideal plating material and therefore most frequently selected for a wide variety of applications. Soft in its pure and annealed form. Good corrosion and temperature resistance. Used in nuclear seals/borated water. Excellent anti-galling properties. Inexpensive.	500 (oxidizing) 1200 (non-oxidizing)	not limited
AP	Gold under Silver	Oxidizing environments above 500°F. As high temperature oxygen permeates the outer silver layer the thin gold layer ensures proper adhesion of the silver.	1200	not limited
GP	Gold (Au)	Soft metal with excellent chemical and oxidation resistance and very high temperature capability. Expensive for larger sizes.	1700	not limited
CP	Copper (Cu)	Relatively soft and inexpensive plating. Good high temperature resistance. Not for use with Waspaloy.	1700	not limited
NP	Nickel (Ni)	Very high temperature capability, but harder than either Silver or Copper even when annealed. Used instead of silver in hot, oxidizing environments.	2200	not limited

Finish Thickness Selection Guidelines

Finish of the mating surfaces is an important factor in selecting the most appropriate plating or coating thickness. Generally, rougher surfaces require thicker finishes to ensure proper sealing. Refer to the appropriate seal cross section in the bar chart below. Locate the flange surface finish in the bar above the seal free height to determine the appropriate finish thickness on the left.



Available Finish Thicknesses	
Finish Thickness Code	P Finish Thickness (inches)
A	0.0005 – 0.001
B	0.001 – 0.0015
C	0.0015 – 0.0025
D	0.002 – 0.003
E	0.0025 – 0.0035
F	0.003 – 0.004
G	0.004 – 0.006
H	0.006 – 0.009
J	0.0035 – 0.005
K	0.005 – 0.007
M	0.004 – 0.005
N	0.001 – 0.002

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Plating Information Silver-Indium

Overview:
Parker Hannifin's Silver-Indium diffused plating is a patent-pending electro-deposited plating process developed for metal seals exposed to hot, oxidizing environments. This new coating is specifically engineered to minimize the blistering and subsequent delamination often seen with plain silver or silver-gold composite coatings.

Figure 1: Blisters seen on a standard silver plated seal after 1,000 hours in air at 500°F

Figure 2: Parker Hannifin's Silver-Indium diffused plating

Current Plating Technology:
Silver plating is typically used to improve the performance of static metal seals by providing a ductile, low-hardness outer layer capable of conforming to irregularities in the mating surfaces. However, silver is easily permeated by oxygen at elevated temperatures, leading to oxidation of the underlying substrate. This oxidation causes the silver plating to lose adhesion and blister. As a result, silver and silver gold composite coatings are generally limited to application temperatures less than 500°F.

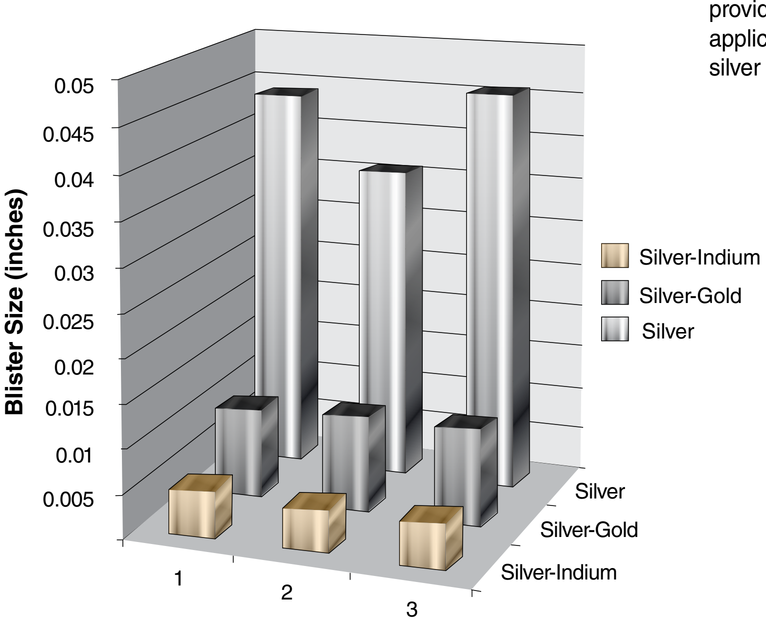

Figure 3: Blister size of Silver, Silver-Gold, and Silver-Indium samples after 500 hours in air at 1150°F.

One method used to combat silver blistering is to add a thin layer of gold between the substrate and the silver plate. The dense gold layer retards the diffusion of oxygen, thereby reducing the incidence of blisters. Although this method is highly effective, it is prohibitively expensive for general or high volume use.

The Parker Solution:
Parker's solution incorporates a unique heat treatment process to diffuse a thin layer of indium into the silver plating, producing a soft but robust surface that is more resistant to high temperature blistering than either silver or silver-gold composite coatings. The diffused indium prevents oxygen diffusion through the plating layer in two ways. First, the indium binds to oxygen at both the surface and within the plating matrix, forming stable oxides. Second, the indium fills inter-spatial voids within the silver plating, effectively blocking atomic diffusion of oxygen atoms, thereby preventing them from reaching the underlying substrate.

Performance:
Long-term testing confirms that Parker's new Silver-Indium diffused plating is significantly better at reducing blister formation and subsequent delamination when compared to plain silver or silver gold composite coatings. And, because Silver-Indium retains its ductility during and after high-temperature exposure, sealing performance is fully maintained.

Applications:
Silver-Indium plating is suitable for use in applications currently using plain silver or silver-gold composite coatings for enhanced sealing performance, including aerospace, automotive, and heavy diesel applications. In addition, the added oxidation resistance provided by Silver-Indium allows it to be used in high temperature applications (up to 1150°F) well beyond the capability of standard silver and silver gold composite coatings.

Metal Seal Platings, Coatings and Finishes
TriCom®

TriCom is a proprietary electrodeposited composite tribological coating developed to provide excellent wear and oxidation protection for metallic sealing systems. TriCom comprises a unique matrix of cobalt co-deposited with chromium carbide (Cr_3C_2) particles to create a wear and oxidation resistant system for prolonged use at 1150°F and limited use at 1250°F.

TriCom is designed to significantly reduce the wear of metallic sealing elements and the respective mating surfaces caused by thermal expansion and vibrational movement.

The unique wear characteristics, excellent bond strength, and ease of application of TriCom make it an excellent candidate for application on thin flexible sealing members. These characteristics provide TriCom a competitive advantage when compared with other coating alternatives. Bond strength testing has been performed to show that TriCom will continue to adhere to a seal under bending loads that would cause a comparable thermal sprayed coating to spall.

Figure 1: TriCom is a composite coating consisting of a cobalt matrix with chromium-carbide reinforcing phase.

Figure 2: Pin on Flat Wear Test Results for Alloy 718 Coated with TriCom and Tribaloy T-800.

Table 1 – TriCom Characteristics	
Hardness (as-coated)	300-350 HVN 29 - 35 HRC
As-Coated Surface Finish	32 µin Ra or better
Coating Thickness	As specified (.001 to .005 in. typical)
Service Temperature	1250° F (621° C) Max.

Coating Structure:
TriCom is a composite coating containing finely dispersed chromium carbide particles (Figure 1). Cobalt in the coating matrix provides high temperature lubricity. Chromium carbide reduces the wear rate by acting as a solid lubricant when partially oxidized. When TriCom is heated in air, cobalt oxide and chromium oxide is formed on the surface of the coating creating a lubricious oxide glaze that protects the coating and counter face from wear. The oxide glaze physically separates the parts and allows them to glide over each other, minimizing wear on both surfaces while preserving sealing integrity.

Coating Performance:
Extensive testing has been performed at ambient and elevated temperatures to characterize the capabilities and service limits of TriCom.

The results of independent ambient temperature wear tests of uncoated, TriCom coated, and Tribaloy T-800 coated samples are presented in (Figure 2). Samples were weighed before and after a linear reciprocating wear test to determine mass lost to wear. TriCom reduced wear of coated and uncoated counter faces to levels lower than T-800 or systems without coatings.

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TriCom® (cont.)

TriCom has also performed well in elevated temperature tests. A coated 10mm diameter ball was tested in linear reciprocating contact at 1350°F. The sample was worn against an uncoated Alloy 718 at a contact stress of 46 ksi for a total distance of 4.9 miles without wearing through the coating (Figure 3).

Table 2 – Test Parameters for Oscillating Wear Tests	
Test Laboratory	IMR Labs, Ithaca, NY
Motion	Oscillatory – 0.1 in stroke (2.54 mm)
Frequency	15 cycles/min.
Test Duration	1000 cycles
Temperature	68° F (20° C)
Contact	Chamfered pin against flat
Contact Stress	14.5 ksi (100 MPa)

In high frequency wear tests at 1350° F (modified ASTM D5707 method), TriCom caused less wear on the counter face than other nickel-cobalt based anti-wear coatings.

Benefits Over Thermal Spray Coatings

Thermal sprayed coatings often need grinding or polishing to meet tight tolerances and ensure a good surface finish. TriCom coated parts are typically coated to net shape with no necessary secondary operations. The coating may be polished or ground to meet a customer's specific requirements if necessary.

The TriCom coating process will not deform thin parts. The thermal spray process will cause dimensional distortion in thin sections as the spray jet impinges upon the part.

Table 3 – Test Parameters for High Temperature Wear Tests	
Test Laboratory	Parker Hannifin Advanced Products, North Haven, CT
Motion	Linear Reciprocating (0.25 inch stroke)
Frequency	145 cycles/min.
Test Duration	622,500 cycles (72 hours)
Temperature	1150° F (621° C)
Contact	10 mm ball on flat
Contact Stress	46.0 ksi (317 MPa)

Applications:
TriCom is typically applied to temperature resistant metals including stainless steel, nickel and cobalt super alloys. TriCom is suitable for use in mildly oxidizing environments, such as air, and carburizing atmospheres including exhaust gasses. Common applications include resilient metal sealing components in land based and aviation gas turbines.

TriCom wears well against most metals, including stainless steel, nickel and cobalt alloys, and cast iron. TriCom should be used in high contact stress systems that experience wear due to differential thermal expansion and vibration. TriCom is best suited for predominately static applications but has been utilized successfully in low speed dynamic systems

Figure 3: TriCom exhibited excellent wear resistance at 1150° F, surviving 4.9 miles of sliding wear on a 10mm ball. Wear scar diameter is 0.022 inches.

Section D
Material Selection

Metal Seal Platings, Coatings and Finishes
TriCom-HT™

TriCom-HT is a proprietary electro-deposited coating developed to provide excellent wear and oxidation resistance for high temperature metal seals and sealing components. TriCom-HT comprises a unique cobalt-nickel alloy matrix co-deposited with chromium carbide (Cr_3C_2) and MCrAlY particles to provide a wear and oxidation resistant system for prolonged use at 1400°F (760°C) and limited exposure up to 1550°F (843°C).

TriCom-HT is designed to significantly reduce the wear of metallic sealing elements caused by thermal expansion and vibrational movement between mating surfaces.

Coating Structure:
TriCom-HT is a composite tribological coating containing finely dispersed reinforcing phases of chromium carbide and MCrAlY particles (Figure 1). Cobalt in the coating matrix provides high temperature lubricity while nickel provides ductility, oxidation resistance and increased hardness to prevent abrasive wear. Chromium carbide reduces the wear rate by acting as a solid lubricant when partially oxidized. MCrAlY is used as a vehicle to introduce strong oxide forming metals into the coating to increase oxidation resistance and coating adhesion to the substrate. Upon heating in air, chromium oxide, alumina and yttria form within the coating matrix, slowing further oxidation of the coating. Cobalt oxide and chromium oxide also form on the coating surface, providing a lubricious oxide glaze that decreases both the coating and counter face wear rates (Figure 2).

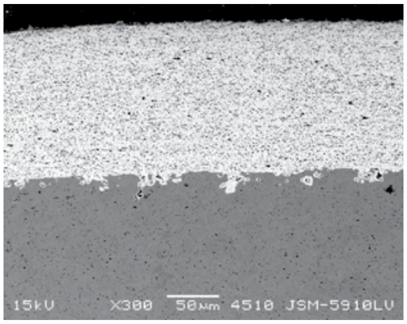

Figure 1: TriCom-HT is a composite coating consisting of a cobalt-nickel matrix with chromium carbide and MCrAlY reinforcing phases.

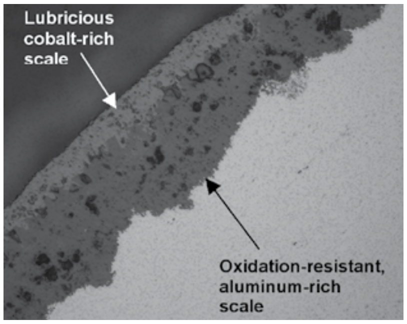

Figure 2: TriCom-HT forms a multi-layer oxide scale at service temperatures to simultaneously slow oxidation and wear.

Coating Performance:
TriCom-HT is designed to balance wear resistance with oxidation resistance to provide a long lasting solution to high temperature wear. TriCom-HT was tested using a high temperature linear reciprocating wear tester to fully evaluate the coating at each stage of development.

The unique composition of TriCom-HT significantly improves oxidation and wear behavior compared to typical cobalt chromium carbide coatings (Figure 3), extending the service temperature and life of the coating. In high temperature, high frequency friction and wear tests (modified ASTM D 5707 method) TriCom-HT coated samples exhibited less wear than samples coated with a cobalt chromium carbide coating. The wear rate of TriCom-HT coated samples remained stable throughout the test temperature range of 1350°F to 1500°F (732°C to 816°C).

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TriCom-HT™ (cont.)

Table 3 compares the oxidation behavior of TriCom-HT to competitive wear resistant coatings at 1350°F (732°C). The oxidation rate of TriCom-HT approximates that of nickel-based coatings, and is an order of magnitude better than typical cobalt chromium carbide coatings.

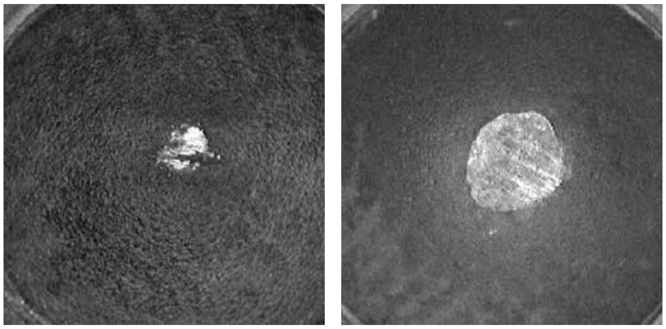

Figure 3: Wear scar on coated spheres from high temperature ball-on-flat wear tests. TriCom-HT (at left) exhibits significantly less wear after 72-hours at 1350°F (732°C) than a typical cobalt chromium carbide coating (right). Contact stress was 46 ksi (317 MPa) and total wear distance was 4.9 miles (7.9 km).

Applications:
TriCom-HT is typically applied to temperature resistant metals including stainless steels, nickel and cobalt superalloys. TriCom-HT works well in both oxidizing environments, such as air, and carburizing atmospheres including exhaust gases.

TriCom-HT is suitable for any high temperature static sealing application where differential thermal expansion or vibrational wear may occur. Typical applications include resilient metal seals, sealing components for land based and aviation gas turbines, and diesel exhaust components.

Figure 4: TriCom-HT prevents wear in high load metal to metal sealing applications such as these automotive exhaust manifold couplers.

Table 1: TriCom-HT Characteristics	
Hardness	450-500 HVN 45 - 49 HRC
As-Coated Surface Finish	64 µin (1.6 µm) Ra or Better
Coating Thickness	As Specified .001 to .005 in. (0.025 to 0.127 mm) Typical
Service Temperature	1400°F (760°C) Continuous 1550°F (843°C) Maximum

Table 2: Test Parameters for High Temperature Wear Tests	
Test Laboratory	Parker Hannifin Advanced Products – North Haven, CT
Motion	Linear Reciprocating (0.25 inch stroke)
Frequency	145 cycles/min
Test Duration	622,500 cycles (72 hours)
Temperature	1350°F (732°C)
Contact	10 mm ball-on-flat
Contact Stress	46.0 ksi (317 MPa)

Table 3: Oxidation Testing at 1350°F for 72 Hours in Air

Coating	Scale Thickness
TriCom-HT	5.8×10^{-4} in
Cobalt Chromium Carbide Coating	1.9×10^{-3} in
Nickel Chromium Carbide Coating	3.5×10^{-4} in

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