Control Valve Material Considerations

The following pages are intended as a general overview of control valve materials.

They are not intended as engineering recommendations or advice.

It is the end user's responsibility to make the final decision regarding the selection of materials based on their knowledge of their process.

Properties

- **Mechanical and Physical Properties**
  - **Yield Strength** – Stress required to cause 0.2% permanent deformation.
  - **Hardness** - Materials resistance to penetration or indentation. Often used to estimate sliding wear resistance and resistance to abrasion and erosion.
  - **Toughness** - Materials ability to absorb energy without fracture. Impact testing. A tough material is not brittle.
- **Wear Properties**
  - **Sliding Wear (galling)**
  - **Erosive Wear**
  - **Cavitation Wear**
- **Corrosion Properties..**

Yield Strength: Stress (force per unit area) that produces 0.2% permanent deformation.

Hardness: Resistance to penetration or indentation. Usually measured by loading an indenter into the material and measuring the depth of penetration or surface area of the indentation. The more the penetration, the less hard the material is

Toughness: The ability of material to absorb energy and deform plastically before fracturing. Usually measured using impact tests. Number of foot pounds required to fracture a stressed sample. A tough material is NOT BRITTLE.

Sliding wear "galling". Occurs when the heat and pressure between irregularities on the surface is high enough to cause localized welding and transfer of material between the sliding parts. PREVENTION: Use materials with dissimilar composition (makes welding less likely). Use materials with different surface hardnesses.

Erosive wear: Caused by high velocity fluid impingement or erosive particles if flow medium.

Cavitation wear: This is discussed at length in the incompressible flow presentation.

Corrosion properties: A materials resistance to corrosion is of course extremely important.

Pressure Effects

- **Inlet and Differential Pressure**
  - **Cavitation**
  - **Flashing**
  - **Erosion**
    - High pressure drop → high velocity
    - Abrasive media, wet steam
  - **Erosion-Corrosion**
    - High velocity → erode passivated layer

The inlet pressure and differential pressure determine whether a liquid will cavitate or flash, both of which cause damage. The damage mechanisms are discussed in the incompressible flow presentation.

Pressure differential affects the velocity and thus the potential for erosion caused by entrained solids, or in the case of steam, moisture drops in wet steam.

Erosion-corrosion results when high velocity fluid streams wash away the “passive layer” that protects many stainless steels.

Temperature Effects

Elevated Temperature

- **Yield Strength**
- **Creep**
- **Coefficient of Thermal Expansion**
  - CS, alloy steel, 410SS → low
  - 300 series SS → high
- **Graphitization of Carbon Steel**
  - > 800F carbides decompose into carbon and iron reducing strength and toughness
- **Sensitization of Stainless Steel**
  - At high temperatures, such as encountered when welding, there is a risk that the chrome will form chrome carbides with any carbon present in the steel. This reduces the chrome available to provide the passive film and leads the potential for corrosion on the portion of the stainless steel affected by the high temperature
  - PWHT
  - 316L..

Increasing temperature reduces yield strength.

At high temperatures a phenomenon called "CREEP" comes into play. Normally, metals are elastic (a certain stress produces a predictable strain. When the stress is removed, the material goes back to its original dimension. At high temperatures the behavior becomes inelastic. The strain will slowly increase with time. Hence the name "creep"

Coefficient of thermal expansion: When heated, metals expand in a predictable way. Carbon steels, alloy steels and 400 series stainless steels have low thermal expansion coefficients. 300 series stainless steels have high thermal expansion rates. This must be kept in mind when selecting valve components: Globe cage must match body, Ball must match body to avoid seizing.

Graphitization: Temperatures above 800 F cause the CARBIDES in carbon steel to decompose into iron and graphite, reducing strength and toughness. Addition of Chromium and Molybdenum make the carbide phase more stable in Chrome Molly steel and 300 series stainless steel.

Sensitization - At high temperatures, such as encountered when welding, there is a risk that the chrome will form chrome carbides with any carbon present in the steel. This reduces the chrome available to provide the passive film and leads the potential for corrosion on the portion of the stainless steel affected by the high temperature.

Common Valve Body Materials

- Carbon Steel
  - Low Material Cost
  - - 20°F (-28°C) to about 800°F (425°C) Max.
- Chrome Moly (alloy steel)
  - Material cost = 1.5 x Carbon Steel
  - To 1200°F (648°C) *
  - Greater Erosion (Flashing) Resistance
- Stainless Steel
  - Material cost = 2.5 x Carbon Steel
  - Cryo. to 1500°F (815°C) *
  - Greatest Erosion Resistance
  - Corrosion Resistant..

* Class 150 flanged ratings terminate at 1000ºF (538ºC).

Carbon steel should not be used above 800 F. It can become brittle at temperatures below -20 deg F.

Raw casting costs are compared to that of carbon steel.

Chrome Moly sees use in power plants due to resistance to flashing damage and high temperature steam. It sees use in refineries because of the elevated temperatures encountered there. Also many high temperature refinery applications are not compatible with 316 ss.

316 ss is corrosion resistant in a great number of applications. It is used in a majority of refinery applications. It is also the most erosion resistant and has the highest temperature capability of the common body materials. 316 is also good for cryogenic temperatures (-150 to –460), where CS and Chrome Moly become brittle.

Stainless Steel

- Selected for corrosion resistance and high temperature properties
- 12% Chrome (minimum)
  - Forms protective layer of Chromium Oxide (Cr_2O_3)
- Three forms
  - Ferritic (430) Fe, Cr (Not normally used in valves)
  - Martensitic (400 series) Fe,Cr,C
  - Austenetic (300 series) Fe,Cr,C,Ni

Body Material Ratings ANSI B16.34

VALVES — FLANGED,
THREADED, AND WELDING END

ASME/ANSI B16.34-1988

TABLE 2-1.1
RATINGS FOR GROUP 1.1 MATERIALS

A 105(a)	A 515 70(a)	A 675 70	A 672 B70(a)
A 216 WCB(a)	A 516 70(a)	A 696 Gr. C	A 672 C70(a)
A 350 LF2(d)	A 537 Cl.1(d)		

NOTES:
(a) Permissible, but not recommended for prolonged usage above about 800°F.
(d) Not to be used over 650°F.

TABLE 2-1.1A STANDARD CLASS

Temperature, °F	Working Pressure by Classes, psig							
	150	300	400	600	900	1500	2500	4500
−20 to 100	285	740	990	1,480	2,220	3,705	6,170	11,110
200	260	675	900	1,350	2,025	3,375	5,625	10,120
300	230	655	875	1,315	1,970	3,280	5,470	9,845
400	200	635	845	1,270	1,900	3,170	5,280	9,505
500	170	600	800	1,200	1,795	2,995	4,990	8,980
600	140	550	730	1,095	1,640	2,735	4,560	8,210
650	125	535	715	1,075	1,610	2,685	4,475	8,055
700	110	535	710	1,065	1,600	2,665	4,440	7,990
750	95	505	670	1,010	1,510	2,520	4,200	7,560
800	80	410	550	825	1,235	2,060	3,430	6,170
850	65	270	355	535	805	1,340	2,230	4,010
900	50	170	230	345	515	860	1,430	2,570
950	35	105	140	205	310	515	860	1,545
1000	20	50	70	105	155	260	430	770

This is an example of a page from ANSI B16.34 which gives pressure/temperature ratings of a broad range of materials used for valve bodies.

Body Material Ratings

Carbon steel

TABLE 2-1.1A STANDARD CLASS

Temperature, °F	Working Pre			
	150	300	400	600
−20 to 100	285	740	990	1,480
200	260	675	900	1,350
300	230	655	875	1,315
400	200	635	845	1,270
500	170	600	800	1,200
600	140	550	730	1,095
650	125	535	715	1,075
700	110	535	710	1,065
750	95	505	670	1,010
800	80	410	550	825
850	65	270	355	535
900	50	170	230	345
950	35	105	140	205
1000	20	50	70	105

Chrome moly

TABLE 2-1.13A STANDARD CLASS

Temperature, °F	Working Press			
	150	300	400	600
−20 to 100	290	750	1,000	1,500
200	260	750	1,000	1,500
300	230	730	970	1,455
400	200	705	940	1,410
500	170	665	885	1,330
600	140	605	805	1,210
650	125	590	785	1,175
700	110	570	755	1,135
750	95	530	710	1,065
800	80	500	665	995
850	65	440	585	880
900	50	355	470	705
950	35	260	350	520
1000	20	190	255	385
1050	20(1)	140	190	280
1100	20(1)	105	140	205
1150	20(1)	70	90	140
1200	20(1)	45	60	90

316 SS

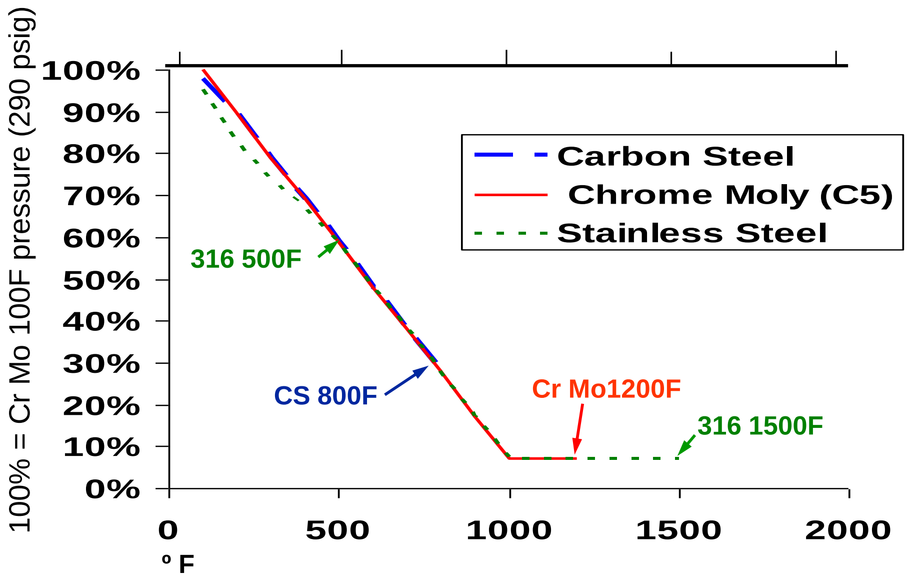
TABLE 2-2.2A STANDARD CLASS

Temperature, °F	Working Press			
	150	300	400	600
−20 to 100	275	720	960	1,440
200	240	620	825	1,240
300	215	560	745	1,120
400	195	515	685	1,030
500	170	480	635	955
600	140	450	600	905
650	125	445	590	890
700	110	430	575	865
750	95	425	565	845
800	80	415	555	830
850	65	405	540	810
900	50	395	525	790
950	35	385	515	775
1000	20	365	485	725
1050	20(1)	360	480	720
1100	20(1)	325	430	645
1150	20(1)	275	365	550
1200	20(1)	205	275	410
1250	20(1)	180	245	365
1300	20(1)	140	185	275
1350	20(1)	105	140	205
1400	20(1)	75	100	150
1450	20(1)	60	80	115
1500	15(1)	40	55	85

It is difficult to compare the tabular data of the common valve body materials, but examining them graphically shows some interesting things. (See next two pages.)

Body Material Ratings

ANSI 150



Cr Mo & 316 flange ratings for class 150 valves terminate at 1000F

In Class 150 the pressure/temperature curves of the three common materials are quite similar.

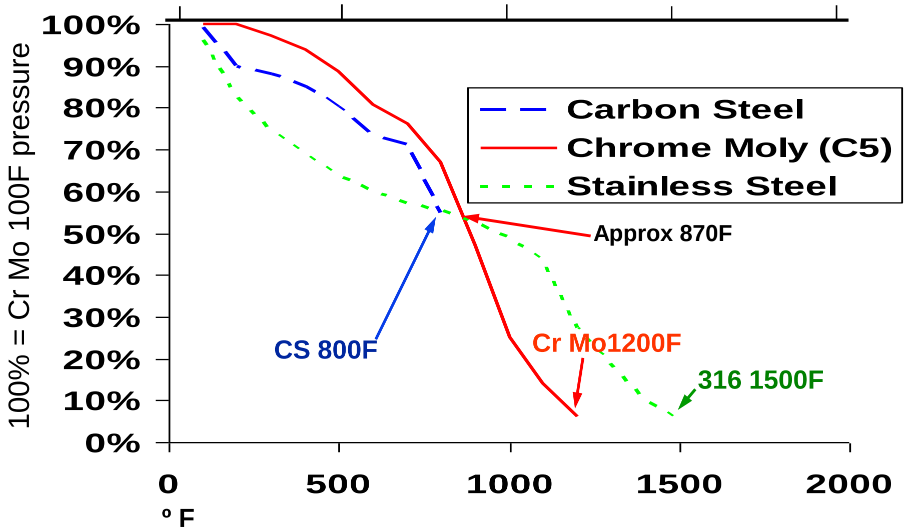
At 100 F, CrMo is 5 degrees higher than carbon steel, then CrMo and CS track each other to 800 F where CS ends.

316 is only slightly lower at lower temperatures, then starting at 500F it tracks the other two as far at they go.

100% on the graph is the 100 F rating for CrMo.

Body Material Ratings

ANSI 300 and up



In Class 300 and above the three materials have quite different pressure/temperature curves.

In Class 300 and above, the shapes of the curves for each pressure class are identical, only the scale is different.

100% on the graph is the 100 F rating for CrMo.

Body Material Temperature Limits

	F		C	
Cast Iron	-20	410	-28	210
Ductile Iron	-20	650	-28	340
Carbon Steel (WCB)	-20	800	-28	425
Carbon Steel (LCB)	-50	650	-45	340
CrMo (WC6)	-20	1000	-28	537
CrMo (WC9)	-20	1050	-28	565
CrMo (C5, C12)	-20	1200	-28	648
SS 304, 316	-425	1500	-253	815
Alloy 20	-50	300	-45	148
Aluminum	-325	400	-198	204
Bronze	-325	550	-198	287
Inconel	-325	1200	-198	648
Monel	-325	900	-198	480
Hastelloy C	-325	1000	-198	537
Titanium		600		315

This is a list of the temperature limits for a wide range of body materials.

Erosion Resistance

- Bronze
- Alloy 20
- Monel
- Hastelloy B & C
- 316 SS
- K Monel
- 17-4 ph
- 416 SS
- Inconel
- Alloy 6 hard facing
- Chrome & Tungsten Carbide
- Ceramic

Note:Top to bottom: worst to best.

This is a list from the ISA Control Valve Handbook, listing relative resistance to erosion.

Relative Resistance to Cavitation Damage

Material	Hours Tested	Index*
Stellite 6 over 316	120	20
17-4 PH 45 Rc	12	2
316 SS	6	1
Carbon Steel	2.25	0.38
Brass	0.5	0.08
Aluminum	(2 Min.)	0.006

*** 316 SS is the reference. The others were tested until they showed approximately the same amount of damage as did the 316 SS sample after 6 hours of testing.**

From ISA Control Valve Handbook

316ss was tested for 6 hours under cavitating conditions. Then the others were tested until they showed approximately the same degree of damage and the time as shown was recorded.

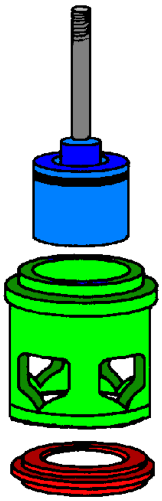
The index was determined by dividing the times required to produce damage in the various materials by the time required to produce equivalent damage in 316

Alloys

Alloying elements are added to basic steels to enhance corrosion resistance, hardness and toughness.

- **Carbon -** carbon is the principal hardener in steel. The more carbon that is added (up to 1.2%), the harder it gets.
- **Molybdenum -**. Molybdenum adds toughness and increases corrosion resistance to chlorides.
- **Chromium -** Protects against corrosion and adds heat resistance.
- **Sulfur -** sometimes added in controlled amounts for easier machining ands welding.
- **Nickel -** improves corrosion resistance and toughness and helps austenitic stainless steels to maintain their austenitic structure.
- **Silicon -** principal deoxidizer used in steel making. It also increases strength and hardness.
- **Vanadium -** Adds toughness and fatigue resistance.
- **Manganese** - contributes to strength and hardness

Valve Trim Material - Internal parts of the valve



Trim Materials vs. Body Materials

- Stronger
- Special characteristics
  - Resist Galling
  - High wear resistance
  - Erosion resistant
  - Corrosion Resistant
- Treated or Coated
  - Chrome Plated, Stellite overlay
- Expensive relative to body material..

Typical Trim Materials (Ball Valves)

Typically selected based on strength & level of corrosion resistance

- Balls and seats
  - 316 SS
  - 410 SS (used in some high temp refinery processes, very expensive
  - Typically coated
  - Usually dissimilar to prevent galling..

Typical Trim Materials (Ball Valves)

Trim Coatings

- **Hard Chrome (HCr)** Balls
  - Coating process – Electroplated
  - Hardness – 64-69 HRC
  - Corrosion resistance similar to 316 SS
  - Not for Chlorides, pH<2, erosive or abrasive media
  - Max. temp – 840 F
- **Cobalt based hard facing (Stellite)** Balls, seats
  - Coating process – PTA (Plasma transferred arc welding)
  - Hardness – 36-43 HRC
  - Resistant to abrasive wear, erosion and better corrosion resistance than hard chrome
  - Max. temp – 1100 F

- **Nickel Boron (NiBo)** Balls
  - Coating process – thermal spray and fuse
  - Hardness – 55-60 HRC
  - Not suitable for corrosive liquids
  - Used in high temp and abrasive applications
  - Better than hard facing in erosive or abrasive media
  - Max. temp – 1100 F
- **Chrome Carbide (CrC)** Balls, seats
  - Coating process – High Velocity Oxy Fuel (HVOF)
  - Hardness – 60-65 HRC
  - Excellent wear and and corrosion resistance
  - Max. temp – 1470 F
- **Tungsten Carbide (WC-Co)** Balls, seats
  - Coating process – High Velocity Oxy Fuel (HVOF)
  - Hardness – 65-70 HRC
  - Excellent wear and and corrosion resistance, especially in high cycle applications
  - Max. temp – 840 F.

The most common coating for balls in metal seated ball valves is hard chrome. Its hardness makes 316SS balls much more wear resistant than bare 316. It does not hold up well with chlorides or very strong acids and is not good for very erosive or abrasive media.

The most common coating for metal seated ball valve seats is Stellite (or a similar material). These hard facing materials are very resistant to abrasive and erosion wear and provide sufficient differential hardness to resist galling when used in conjunction with hard chrome plated balls. Balls can also be hard faced, but the machining can be expensive.

Nickel Boron coating on balls (usually used in conjunction with hard faced seats) is used at high temperatures and for very erosive media (but not with corrosive liquids)

Chrome carbide has excellent wear and corrosion resistance and can be applied at the highest temperatures of the common coatings.

Tungsten Carbide gives good service in high cycle applications..

Typical Trim Materials (Ball Valves)

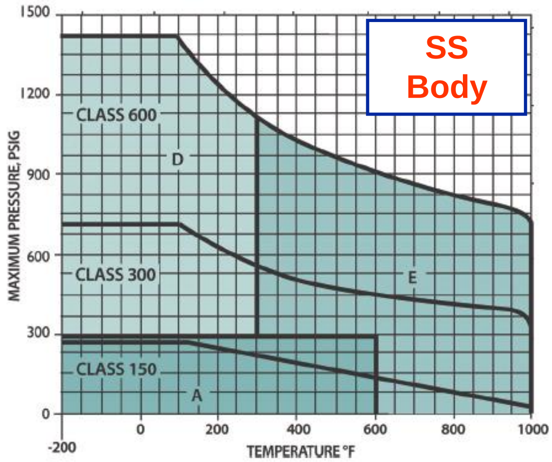
- **Shafts**
  - 316
  - 17-4PH
  - XM-19 (Nitronic 50, Carlson Alloy)..

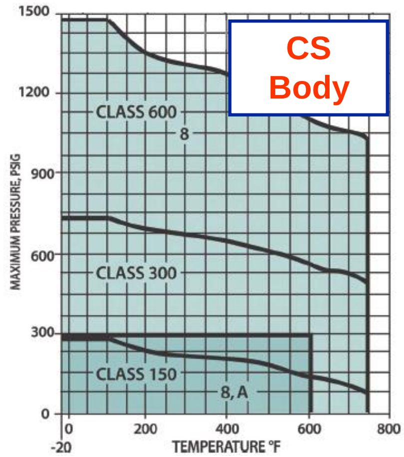
316 SS shafts have good corrosion resistance and moderate strength, and are suitable for many soft seated ball and butterfly applications

17-4PH is a precipitation hardening stainless steel that is very strong. Before the precipitation hardening heat treatment it is easily machineable. After it has been machined, a single low temperature (900F for 1 hour) heat treatment can be applied to increase the strength and hardness of the steel. This is known as “age-hardening.” 17-4 PH is much stronger than 316SS and is used in applications where torque requirements are too high for 316SS. It is not as corrosion resistant as 316SS. Not used above 800F

Nitronic 50 is a trade name of Carlson Alloy for XM-19 Stainless steel. Similar corrosion resistance to 316 and 317 with twice the yield strength. Not as strong as 17-4PH, but retains its strength well above 800F

Globe Valve Trim Considerations





Trim Code	Plug	Seat Ring	Cage	Stem
A	316 SS	316 SS	316 SS/CP	316 SS
D	316 SS/HFS	316 SS/HFS	316 SS/CP	316 SS
E	316 SS/HFS+G	316 SS/HFS	316 SS/CP	316 SS

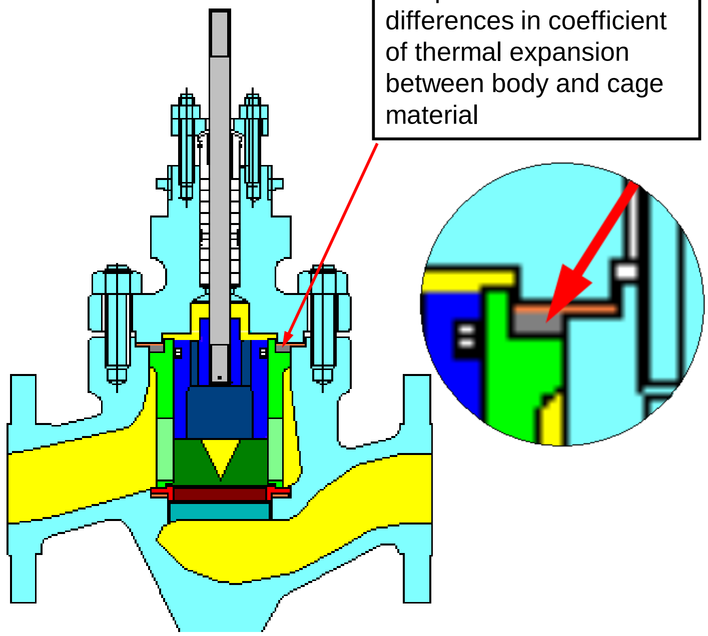
Trim Code	Plug	Seat Ring	Cage	Stem
8	416 SS	416 SS	17-4PH/CP	316 SS
A	316 SS	316 SS	316 SS/CP	316 SS

This is an example of how we use trim materials in globe valves that have compatible coefficients of thermal expansion with the various body materials.

When 316 stainless steel is used for a globe valve body and bonnet, the cage, which is trapped between the body and the bonnet (this is illustrated on the next page) must also be 316 stainless steel so that the body and cage will have the same coefficient of thermal expansion.

Globe Valve Trim Considerations

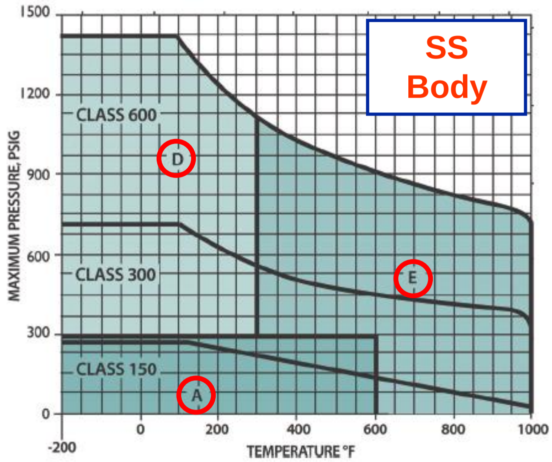
- Cage is trapped between the body and bonnet
- Cage and body must have similar thermal expansion coefficients
- Plug and cage must have similar thermal expansion coefficients

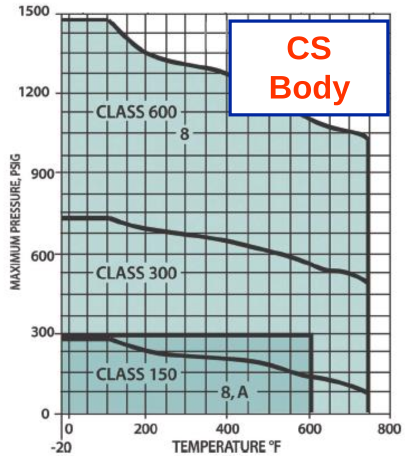


Spiral wound gasket compensates for minor differences in coefficient of thermal expansion between body and cage material

The figure illustrates how the cage in a cage guided valve is trapped between the body and bonnet.

Globe Valve Trim Considerations





Trim Code	Plug	Seat Ring	Cage	Stem
A	316 SS	316 SS	316 SS/CP	316 SS
D	316 SS/HFS	316 SS/HFS	316 SS/CP	316 SS
E	316 SS/HFS+G	316 SS/HFS	316 SS/CP	316 SS

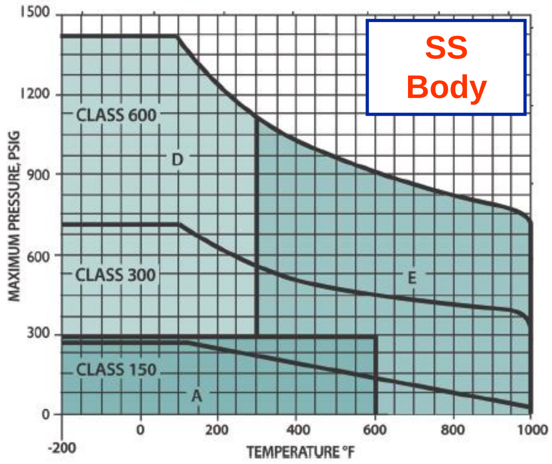
Trim Code	Plug	Seat Ring	Cage	Stem
8	416 SS	416 SS	17-4PH/CP	316 SS
A	316 SS	316 SS	316 SS/CP	316 SS

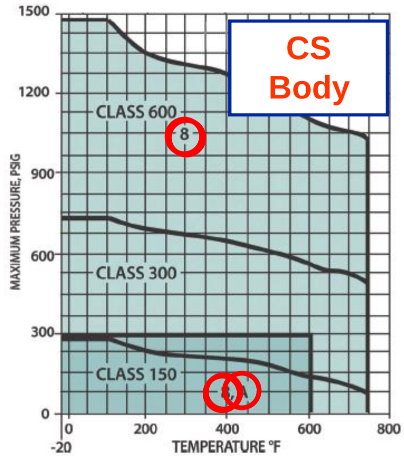
This manufacturer offers three standard trim configurations for their 316 stainless steel valve, all of which have a 316 SS cage. The plug and seat ring must also have thermal expansion properties that are similar to the cage to maintain proper clearances. Because the plug and cage are both 316 stainless steel, the inside of the cage is chrome plated to avoid galling.

For higher pressures the seating surfaces of the plug and seat have a Stellite overlay to give a very hard seating surface (HFS means “Hard Faced Seat.”)

For high temperatures, the guiding surface of the plug is also hard faced because 316 ss becomes softer at high temperatures. (HGS+G means “Hard Faced Seat and Guide.”)

Globe Valve Trim Considerations





Trim Code	Plug	Seat Ring	Cage	Stem
A	316 SS	316 SS	316 SS/CP	316 SS
D	316 SS/HFS	316 SS/HFS	316 SS/CP	316 SS
E	316 SS/HFS+G	316 SS/HFS	316 SS/CP	316 SS

Trim Code	Plug	Seat Ring	Cage	Stem
8	416 SS	416 SS	17-4PH/CP	316 SS
A	316 SS	316 SS	316 SS/CP	316 SS

The standard trim offering for this manufacturer's carbon steel body globe valve uses a cage made of 17-4 PH stainless steel which has thermal expansion characteristics similar to carbon steel. The plug and seat are 416 stainless steel, which is very hard and has similar thermal expansion characteristics to carbon steel.

At lower temperatures (below 600F) differential expansion between the body and cage are not so important, so as an option, this manufacturer offers a 316 SS cage, plug and seat for improved corrosion resistance.

If corrosion is not a problem, the 17-4 / 416 combination is preferred, since there is less difference between the coefficients of thermal expansion and the seating and guiding surfaces are much harder.

Corrosion & Chemical attack

- Corrosion
  - a destructive chemical process; most often applied to the conversion of a metal to one of its compounds, for example, the corrosion of iron by oxygen and water to produce iron oxides (rust)
  - All metals corrode; in our normal atmosphere of 21% oxygen, all metals except gold, platinum, and palladium corrode spontaneously
- Chemical attack
  - The chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties.

The next two pages are a corrosion guide that was originally published by a globe valve manufacturer a number of years ago. It is this author's observation that the valve manufacturer that published them is knowledgeable of control valve subjects.

However, this author has not personally verified the correctness of the corrosion guide. It is presented here with no warranty as to its correctness or applicability.

It is not intended as engineering recommendations or advice.

It is the end user's responsibility to make the final decision regarding the selection of materials based on their knowledge of their process.

	CAST IRON	CARBON STEEL	17-4PH	420 or 440 ss	416 ss	316 ss	ALLOY 20	HASTELLOY C	MONEL	NICKEL	STELLITE*	HASTELLOY B	TITANIUM
Acetic Acid 100% 24°C(75°F)	X	X	A	X	X	A	A	A	B	B	A	A	A
<50% Boil	X	X	A	X	X	A	A	A	X	X	A	A	A
>50% Boil	X	X	X	X	X	C	A	A	X	X	A	B	A
Acetic Anhydride Boil	X	X	B	X	X	B	A	A	B	B	A	A	A
Acetone	B	B	A	C	C	A	A	A	A	A		A	A
Acetylene	A	A	A	A	A	A	A	A	A	A		A	A
Alcohols	B	B	A	A	A	A	A	A	A	A		A	A
Alum Solution (K)	C	C	C	C	B	A	B	B	B	B	A	B	A
Alumnium Acetate	X	X	B	B	B	B	B	B	B	B		B	A
Aluminum Chloride	X	X	C	X	X	B	A	A	B	C		A	
Aluminum Hydroxide	B	B	B	B	B	B	B	B	B	B		B	A
Aluminum Sulphate < 10% Boil	X	X	A	X	X	A	A	A	C	C		A	A
> 10% Boil	X	X	B	X	X	A	A	A	C	C		A	A
Amines	A	A	A			A			B	B			
Ammonia (Anhydrous)	A	B	A			A	A	A	A	A		A	
Ammonium Bicarbonate	C	C				B			X	X			
Ammonium Carbonate	B	B		B	B	B	B	B			A	B	
Ammonium Chloride < 10% Boil	X	X	C				A	A	B	B			A
> 10% Boil	X	X						A	B	B			A
Ammonium Hydroxide		B	A	A	A	A	A						A
Ammonium Nitrate	X	A	A	B	B	A	A	B	X	X			
Ammonium Oxalate	X	X		C	C	B		B	X	X			
Ammonium Persulphate 5%	X	X	B	C	C	B	B	B	B	B		B	
Ammonium Phosphate 5%	X	X				B		B	B	B			
Ammonium Sulphate < 10%	X	X	B	C	C	B	B	B	B	B			
Ammonium Sulphite Boil	X	X		X	X	B	B	B	X	X			
Amyl Acetate	B	B	A	A	A	A	A	A	A	A			A
Amyl Chloride	C	B				A	A		B	B			A
Aniline	A	A				A	A	B	B	B			A
Aniline Hydrochloride						B	B		B	X		B	A
Animal Fat & Oil						A	A	A		A			
Antimony Trichloride	X	X		X	X	X	X	B	B	B		B	X
Arsenic Acid	X	X		X	X	B	B	B	X	X			
Barium Carbonate	C	C				C		B	B	B		B	
Barium Chloride <5%	C	C	B	X	X		B	A	B	B		A	A
> 5%	X	X	B	X	X		B	B	B	B		A	A
Barium Hydroxide	C	C	A	C	C	A	A	B	B	A		B	
Barium Nitrate	C	C				A	A	B	C	C		B	
Barium Sulphate	C	C				B	B	B	B	B			A
Barium Sulphide	X	C				B	B	X	X	B		X	A
Beer	X	X	A	C	C	A	A	A	A	A			
Benzoic Acid	B	B	A	A	A	A	A		A	A			
Benzene (Benzol)	B	B	B	X	X	B	A	B	A	A		B	A
Black Liquor (Sulfate)	C	C	A	A	A	A	A	A	A	A			
Blood			A			A	A		A	A			
Boric Acid	X	X	A	B	B	A	B	A	B	B		A	A
Brines (Calcium)	C	C					C	A	A	A	A	A	
Brines (Sodium)	C	C					C	B	A	A	A	B	
Bromine Water						C	B					B	
Butyric Acid Dil.	X	X				B	B	A				A	A
Conc.	X	X				B	B	A				A	A
Butyl Acetate	X	X				B	B		B	B			
Calcium Bisulfate	C	C				B	B	B				B	A
Calcium Carbonate	B	A				A	B	B	B	B			
Calcium Chloride < 20%	B	B	B	C	C	B	B	A	A	A		A	A
Calcium Hydroxide Boil 10%	B	B				B		A	B	B			
20% Boil	B	B				B		A	C	C			
30% Boil	C	C				C		A	C	C			
Calcium Hypochlorite < 5%	X	X				B		A	X	X	A		A
Calcium Sulfate	C	C	B	X	X	B		B	B	B		B	A
Carbolic Acid Phenol 90%	C	C	B	X	X	B	A	A	A	A		A	A
Carbonated Beverage							A	A		A			
Carbonic Acid > 90%	C	B	B	X	X	B		A				A	
Carbon Bisulfide	B	B		X	X	B	B		B	B			A
Carbon Dioxide	A	A	A	A	A	A	A	A	A	A		A	A
Carbon Disulfide	A	A				A	A						
Carbon Monoxide	A	A	A	A	A	A	A	A	A	A		A	A
Carbon Tetrachloride Dry			A	A		A			A	A			A
Carbon Tetrachloride Wet						C			B	B			B
Cellulose Acetate	C	C		X	X	B	B	B	A	A		B	A
Chloroacetic Acid	X	X		X	X	X	X	B	C				A
Chlorinated Water	X	X		X	X	X	B	A					A
Chlorine Gas Dry	X	B	C	X	X	C	B	A	B	X			
Wet	X	X	X	X	X	X	X	C	X	X			
Liquid													
Chlorobenzene	B	B				B	B	B	B	B		B	A
Chloroform Dry 100% 24°C(75°F)	A	A	B	X	X	B	B		A	A		B	A
Chromic Acid < 10% Boil	X	X	C	X	X	C	B	B					A
Chromic Acid > 10% Boil	X	X	X	X	X	X	B	B					A
Citric Acid Dil. 52°C(125°F)	X	X	B	X	X	A	A	A	B	B			A
Citric Acid < 50% 52°C(125°F)			X	X	X	A	A	A	B	B		A	A
Copper Acetate < 20%				X	X	B	A	B	A	A			
Copper Chloride													A
Copper Nitrate Conc. 93°C(200°F)	X	X		X	X	B	B	X	X	X		X	
Copper Sulfate < 40% 93°C(200°F)	X	X	B	X	X	B	A	A	X	X		A	A
Creosote 100°C(212°F)	B	A	B	X	X	B	B		B	B			
Cresylic Acid		A				A	B	B				B	
Cupric Chloride < 5% 24°C(75°F)								B				B	B
Cyanide Solution (Plating)	B	B				B	B	B	B	B		B	B
Cyanogen Gas 100% 24°(75°F)						B	B						
Dichloroethane 100% 100°(212°F)	B	B				B	B	B	B	B		B	A
Ether	B	B	B	B	B	B	A	B	B	B		B	A
Ethyl Acetate	C	C	A	X	X	A	A	B	B	C		B	A
Ethyl Chloride Dry	C	A	A	B	B	A	A	B	B	X		B	A
Ethylene Glycol	A	B	A	B	B	A	A	B	B				A
Fatty Acids 100°C(212°F)	X			B	B	A	A	A	B	A		A	A
Ferric Chloride < 1% 24°C(75°F)	X	X		X	X	X	X	A	X	X		A	A
Ferric Chloride > 1%	X	X		X	X	X	X	A	X	X		A	A
Ferric Chloride Hot < 1%	X	X		X	X	X	X	X	X	X			A
Ferric Chloride Hot > 1%	X	X		X	X	X	X	X	X	X			A
Ferric Hydroxide						B	B						
Ferric Nitrate 5%	X	A	B			B	A	B					
Ferric Sulphate 5%	X	X	B			A	A	A		B			A
Ferrous Chloride 10%	X	X				X		B				B	A
Ferrous Sulphate 10%	X	X	B	C	C	B	A	A	X	X		A	A
Fluorine Gas Dry	X	B		B	B	A	A		A	A			A
Fluorine Gas Wet									B	B			
Formaldehyde 40%	X	B	A	B	B	A	A	B	A	A		B	
Formic Acid < 50%	X	X	B	X	X	X	A	B	A	A		B	
Formic Acid > 50%	X	X	B	X	X	X	A	B	A	B		B	
Formic Acid < 50% 93°C(200°F)	X	X	X	X	X	X	A	B	B	C		B	
Formic Acid > 50% 93°C(200°F)	X	X	X	X	X	X	B	C	C	C		C	
Foods							A	A					
Freon Wet	B	B	B	B	B	A	A	A	A	A		A	
Furfural	B	B	B	B	B	A	A		B				
Gallic Acid				B	B	B	B		C	C			
Glucose													
Glycerine													
Green Liquor (NaOH)	C	C	A	A	A	A	A		A	A			
Hydrochromic Acid													
Hydrocarbons Crude & Refined	A	A	A	A	A	A	A	A	A	A			
Hydrochloric Acid < 1%	X	X							B	B		A	B
Hydrochloric Acid 1-20%	X	X							C	C		B	B
Hydrochloric Acid > 20%	X	X										B	C
Hydrochloric Acid < 1/2% 80°C(175°F)	X	X										B	C
Hydrochloric Acid > 2% 80°C(175°F)	X	X										B	C
Hydrocyanic Acid < 40%	X	X				B	B						
Hydrocyanic Acid > 40%	X	X				B	B						
Hydrogen Chloride Gas Dry	X	X							B	B			
Hydrogen Chloride Gas Wet	X	X							X	X			
Hydrogen Fluoride Dry 100%		A				A	A	B	B	A			
Hydrogen Sulfide Dry			B	C	C	A	A		B	B			A
Hydrogen Sulfide Wet						B	B		C	C			A

KEY TO RATING SYMBOLS: A RECOMMENDED B FAIR C PROBABLY UNSUITABLE X UNSATISFACTORY

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	CAST IRON	CARBON STEEL	17-4PH	420 or 440 ss	416 ss	316 ss	ALLOY 20	HASTELLOY C	MONEL	NICKEL	STELLITE*	HASTELLOY B	TITANIUM
Iodine Dry 100%			B			B		A	A	A			
Lactic Acid 5%	X	X	B	X	X	A	A	B					A
10%	X	X	X	X	X	A	A	B					A
5% Boil	X	X	X	X	X	B	B	C					A
10% Boil	X	X	X	X	X	B	B	C					A
Lead Acetate						B	B	C	C	C			A
Magnesium Chloride 5% Hot		B	C			B	A	A	B	A		A	A
Magnesium Hydroxide	B	B	A			A	A	B	B	A		B	
Magnesium Sulfate	C	B	A	A	A	A	A	A	A	A		A	A
Mercury	A	A		A	A	A	A	B	B	B		B	
Mercuric Chloride < 2%								C					A
> 2% Boil								X					A
Mercuric Cyanide	X	X		X	X	X		C	X	X			
Methyl Chloride Dry						A	A		B	B			
Mine Water (Acid)			A	A	A	A	A	A	A	A			
Molybdic Acid < 5%						B	B						
Natural Gas (Liquid)						A	A	A					
Nickel Chloride						B						A	
Nickel Sulfate						B	A						
Nitric Acid 20%			A			A	A					A	A
20% Boil			X			B	A					A	A
65%			X			C	B					B	A
Conc. Boil			X			X	X					X	A
Fuming			X			X	X					X	A
Nitrobenzene 100%		A				B	B	A	B	B		A	A
Nitrous Acid	X	X				C	C						
Oleum See Sulfuric Fuming													
Oxalic Acid 10%	X	X	B	C	C	B	A	B	B			B	
10% Boil	X	X	X	C	C	C	A	B	C			B	
50% Boil	X	X	X	X	X	X	B	C	X			C	
Oxygen	A	A	A	A	A	A	A	A	A	A		A	A
Perchloroethylene	B	B				B	B		A	A			A
Phenol	B	A				A	A	A	A	A		A	
Phosphoric Acid 10%	X	X	B			A	A					A	
10-50%	X	X	B			A	A					A	
> 50%	X	X	C			B	B					A	
> 20% 175°F	X	X	X			B	B					A	
< 10% Boil	X	X	X			C	C					A	
85% Boil	X	X	X			X	X					B	
Phosphorous Trichloride Dry 100%	B	A				A				A		A	A
Phthalic Anhydride 100%	A	A		B	B	A	A	A	A	A		A	
Picric Acid < 38°C(100°F)	X	X	C			B	B						
Potassium Bromide < 40%	X	X	C			B	B	A	B	B		A	A
Potassium Carbonate	B	B	A	B	B	A	B	B	B	B		B	A
Potassium Chlorate < 40% < 93°C(200°F)	X	X	B	B	B	A	B	B	X	X			A
Potassium Chloride < 40% < 93°C(200°F)	X	X	B	C	C	A	A	B	B	B		B	A
Potassium Cyanide	X	X				B	B			B			
Potassium Ferricyanide < 20%	X	X	B	C	C	B	B	B	B	B		B	
Potassium Hydroxide 50%	B	B	B	C	C	B	B	B	A	A			
30% 80°C(175°F)	B	C	B	C	C	B	B	B	A	A			
50% 80°C(175°F)	X	X	C	X	X	B	B	B	A	A			
30% Boil	X	X	X	X	X	X	X		A	A			
50% Boil	X	X	X	X	X	X	X		B	A			
Potassium Hypochlorate Dil.	X	X						B				B	A
Potassium Iodide	X	X	B			B	B	B	B	B		B	A
Potassium Nitrate	A	A	B	B	B	B	B	B	B	B		B	
Potassium Permanganate Dil.	X	X	B	B	B	B	B	B	B	B			
Potassium Sulfate Dil.	X	X	A	B	B	A	A	A	A	A		A	A
Potassium Sulfate Dil. Boil	X	X				B	A	B	B	B		B	
Potassium Sulfide Sat.	B							B					A
Propane (Liq. Gas) 100%	A	A	A	A	A	A	A	A	A	A		A	A
Propionic Acid	X	X	X	X	X	B		A	B				
Pyrogallic Acid < 100%	X	X	B			B	A	A				A	
Pyroligneous Acid < 20%	X	X				A	A		B				
Quinine Bisulfate						B	B	B				B	
Quinine Sulfate	X	X	B	B	B	B	B	B	B	B		B	
Rosin (Molten)	X	X	B	C	C	B			A	A			
Salicylic Acid	X	X				B	B						
Sewage	A	A	A	A	A	A	A	A					
Silver Bromide < 20%			C				B	A				A	
Silver Chloride							C	C				C	
Sodium Cyanide	B	B	B			B	B						
Sodium Fluoride 5%			B			B	B						
Sodium Hydroxide 50%	B	B	A	B	B	A	A	A	A	A		A	A
< 40% 80°C(175°F)	B	B	A	B	B	A	A	A	A	A		A	A
40-75% 80°C(175°F)	C	C	B	B	B	A	B	B	A	A		B	B
< 30% Boil			B	C	C	B	C	C	B	A		C	
> 30% Boil			C	X	X	C	X	X	B	A		X	
Molten									C	B			
Sodium Hypochlorite < 10% < 24°C(75°F)	X	X	X			C		A				A	
Sodium Hyposulfite	X	X				C		B				B	
Sodium Nitrate	B	B	B	C	C	A	A	B	B	B		B	
Sodium Perborate < 20%	B	B	B			B	B	B	B	B		B	
Sodium Peroxide	B	B	B			B	B	B	B	B		B	
Sodium Phosphate	A	A	B	B	B	B	B	B	B	B		B	A
Sodium Salicylate < 20% 24°C(75°F)						B	B						
Sodium Stannate < 50% 93°C(200°F)	B	B	B	C	C	B	B	B	B	B		B	A
Sodium Sulfate < 40% 100°C(212°F)	C	C	B			A	A	B				B	
Sodium Sulfide < 93°C(200°F)			A			A	A	B				B	
Sodium Sulfite < 20% < 80°C(175°F)	X	C	A			A	A	B	B	B			
Sodium Thiosulfate < 20% < 80°C(175°F)			B			B	B						
Stannic Chloride < 5%	X	X				C	B						
> 5%	X	X				X	C						
Stannous Chloride < 20% < 80°C(175°F)	X	X				A	A					B	
Steam 100°C(212°F)	A	A	A	A	A	A	A				A		
320°C(600°F)		A				A	A				A		
Sulfate Pulp Liquor	C	C	B			B	A						
Sulfite Pulp Liquor	C	A			B	A							
Sulfur (Molten)						A	A	A	B	B		A	
Sulfur Chloride	X	X				X	B	B		B			
Sulfur Dioxide Dry	X	X	A			A	A	A					
Sulfur Dioxide Wet	X	X	C			B	B						
Sulfuric Acid < 2%	X	X	B				A	A	A			A	
2-40%	X	X					A	A	A			A	
> 95% Conc.	A	A	B			B	A	A	A			A	
10-60% Boil	X	X					B		C			A	
Fuming	X	X											
Sulfurous Acid	X	X				B	A	B				B	
Tannic Acid (Sat.)	X	X	B			B	B						A
Tar (Hot)	A	A	A	A	A	A	A						
Tartaric Acid	X	X	A	C	C	A	A	B	B	B		B	A
Tin Chlorides < 10%	X	X					B					B	A
Titanium Sulfate < 10%						B	B					B	
Trichloroethylene 24°C(75°F)	A	A	A	A	A	A	A	A	A	A			
Trichloroacetic Acid								B				B	A
Turpentine 24°C(75°F)	B	B	A	B	B	A	A		B	B			
Water Fresh	B		A	B	B	A	A	A	A	A		A	A
Sea			C			C	A	A	A	A		B	
Mine	X	X	B			B	A						
Distilled	A	B	A			A	A		A	A			
White Liquor	C	C	A	A	A	A	A		A	A			
Zinc Chloride 5% 24°C(75°F)			C			A	A		B	B		B	A
5% Boil			C				A		B	B		B	A
Zinc Sulfate						A	A	B	B	B		B	

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