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 hardesses.
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 $\rightarrow$ high velocity
    - Abrasive media, wet steam
  - Erosion-Corrosion
    - High velocity $\rightarrow$ 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.
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$_2$O$_3$)
- Three forms
  - Ferritic (430) Fe, Cr (Not normally used in valves)
  - Martensitic (400 series) Fe, Cr, C
  - Austenetic (300 series) Fe, Cr, C, Ni
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.
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.)
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 as they go.

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

<table>
<thead>
<tr>
<th>Material</th>
<th>F (°F)</th>
<th>C (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron</td>
<td>-20</td>
<td>410</td>
</tr>
<tr>
<td>Ductile Iron</td>
<td>-20</td>
<td>650</td>
</tr>
<tr>
<td>Carbon Steel (WCB)</td>
<td>-20</td>
<td>800</td>
</tr>
<tr>
<td>Carbon Steel (LCB)</td>
<td>-50</td>
<td>650</td>
</tr>
<tr>
<td>CrMo (WC6)</td>
<td>-20</td>
<td>1000</td>
</tr>
<tr>
<td>CrMo (WC9)</td>
<td>-20</td>
<td>1050</td>
</tr>
<tr>
<td>CrMo (C5, C12)</td>
<td>-20</td>
<td>1200</td>
</tr>
<tr>
<td>SS 304, 316</td>
<td>-425</td>
<td>1500</td>
</tr>
<tr>
<td>Alloy 20</td>
<td>-50</td>
<td>300</td>
</tr>
<tr>
<td>Aluminum</td>
<td>-325</td>
<td>400</td>
</tr>
<tr>
<td>Bronze</td>
<td>-325</td>
<td>550</td>
</tr>
<tr>
<td>Inconel</td>
<td>-325</td>
<td>1200</td>
</tr>
<tr>
<td>Monel</td>
<td>-325</td>
<td>900</td>
</tr>
<tr>
<td>Hastelloy C</td>
<td>-325</td>
<td>1000</td>
</tr>
<tr>
<td>Titanium</td>
<td>600</td>
<td>315</td>
</tr>
</tbody>
</table>

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.
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 ss.
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 and 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**

<table>
<thead>
<tr>
<th><strong>Hard Chrome (HCr) Balls</strong></th>
<th><strong>Nickel Boron (NiBo) Balls</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Coating process – Electroplated</td>
<td>- Coating process – thermal spray and fuse</td>
</tr>
<tr>
<td>- Hardness – 64-69 HRC</td>
<td>- Hardness – 55-60 HRC</td>
</tr>
<tr>
<td>- Corrosion resistance similar to 316 SS</td>
<td>- Not suitable for corrosive liquids</td>
</tr>
<tr>
<td>- Not for Chlorides, pH&lt;2, erosive or abrasive media</td>
<td>- Used in high temp and abrasive applications</td>
</tr>
<tr>
<td>- Max. temp – 840 F</td>
<td>- Better than hard facing in erosive or abrasive media</td>
</tr>
<tr>
<td>- Max. temp – 840 F</td>
<td>- Max. temp – 1100 F</td>
</tr>
<tr>
<td><strong>Cobalt based hard facing (Stellite) Balls, seats</strong></td>
<td><strong>Chrome Carbide (CrC) Balls, seats</strong></td>
</tr>
<tr>
<td>- Coating process – PTA (Plasma transferred arc welding)</td>
<td>- Coating process – High Velocity Oxy Fuel (HVOF)</td>
</tr>
<tr>
<td>- Resistant to abrasive wear, erosion and better corrosion resistance than hard chrome</td>
<td>- Excellent wear and and corrosion resistance</td>
</tr>
<tr>
<td>- Max. temp – 1100 F</td>
<td>- Max. temp – 1470 F</td>
</tr>
<tr>
<td><strong>Nickel Boron (NiBo) Balls</strong></td>
<td><strong>Tungsten Carbide (WC-Co) Balls, seats</strong></td>
</tr>
<tr>
<td>- Coating process – High Velocity Oxy Fuel (HVOF)</td>
<td>- Coating process – High Velocity Oxy Fuel (HVOF)</td>
</tr>
<tr>
<td>- Excellent wear and and corrosion resistance, especially in high cycle applications</td>
<td>- Excellent wear and and corrosion resistance, especially in high cycle applications</td>
</tr>
<tr>
<td>- Max. temp – 840 F.</td>
<td>- Max. temp – 840 F.</td>
</tr>
</tbody>
</table>

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.
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.
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.”)
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.
<table>
<thead>
<tr>
<th>Acetic Acid 100% 24°C (75°F)</th>
<th>Cast Iron</th>
<th>Carbon Steel</th>
<th>12-Ph</th>
<th>400°F</th>
<th>650°F</th>
<th>Allsteel 20</th>
<th>Hastelloy C</th>
<th>Monel</th>
<th>Nickel</th>
<th>Stellite-B</th>
<th>Stainless-Titanium</th>
</tr>
</thead>
<tbody>
<tr>
<td>X X X X X A A A B A A</td>
<td>C C C C C</td>
<td>B B B B B A A</td>
<td>X X X X X A C A</td>
<td>X X X X X A A</td>
<td>A A A A A A A A</td>
<td>X X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Celulose Acetate</td>
<td>C C C C C</td>
<td>B B B B B A A</td>
<td>X X X X X A C A</td>
<td>X X X X X A A</td>
<td>A A A A A A A A</td>
<td>X X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Chloroformic Acid</td>
<td>C C C C C</td>
<td>B B B B B A A</td>
<td>X X X X X A C A</td>
<td>X X X X X A A</td>
<td>A A A A A A A A</td>
<td>X X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Chlorinated Water</td>
<td>X X X X X A C A</td>
<td>B B B B B A A</td>
<td>X X X X X A C A</td>
<td>X X X X X A A</td>
<td>A A A A A A A A</td>
<td>X X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Chromic Acid</td>
<td>X X X X X A C A</td>
<td>B B B B B A A</td>
<td>X X X X X A C A</td>
<td>X X X X X A A</td>
<td>A A A A A A A A</td>
<td>X X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Chromic Acid Dil. 52°C (125°F)</td>
<td>X X X X X A C A</td>
<td>B B B B B A A</td>
<td>X X X X X A C A</td>
<td>X X X X X A A</td>
<td>A A A A A A A A</td>
<td>X X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Chromic Acid Dil. 95°C (203°F)</td>
<td>X X X X X A C A</td>
<td>B B B B B A A</td>
<td>X X X X X A C A</td>
<td>X X X X X A A</td>
<td>A A A A A A A A</td>
<td>X X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Citric Acid</td>
<td>X X X X X A C A</td>
<td>B B B B B A A</td>
<td>X X X X X A C A</td>
<td>X X X X X A A</td>
<td>A A A A A A A A</td>
<td>X X X X X X X</td>
<td>X X X X X X</td>
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<td>X X X X X X</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Copper Acetate</td>
<td>X X X X X A C A</td>
<td>B B B B B A A</td>
<td>X X X X X A C A</td>
<td>X X X X X A A</td>
<td>A A A A A A A A</td>
<td>X X X X X X X</td>
<td>X X X X X X</td>
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<td>X X X X X X</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Copper Chloride</td>
<td>X X X X X A C A</td>
<td>B B B B B A A</td>
<td>X X X X X A C A</td>
<td>X X X X X A A</td>
<td>A A A A A A A A</td>
<td>X X X X X X X</td>
<td>X X X X X X</td>
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</tr>
</tbody>
</table>

**Key to Rating Symbols:**

- **A** = Recommended
- **B** = Fair
- **C** = Probably Unsuitable
- **X** = Unsatisfactory

*A "B" rating may be used for bodies, but additional judgement should be used before applying to trim. For further information, refer to Bulletin T101-1.*