Materials of Construction

REFERENCES

1. Turton, R., Baillie, R. C., Whiting, W. B., Shaeiwitz, J. A., *Analysis, Synthesis and Design of Chemical Processes,* 2nd ed., Prentice Hall, 2003.
   Pages 162-175: Table 5.9

2. Perrys's 6th ed., Section 23.

3. Perry's 7th ed., Section 23. Table 23-2 contains corrosion data for various materials.

4. Peters and Timmerhaus, 5th ed., Chapter 10. Table 10-8 contains chemical compatibility charts.

5. G. N. Kirby, "How to Select Materials," *Chemical Engineering,* Nov. 3, 1980.

6. C. P. Dillon, *Materials Selection for the Chemical Process Industries,* McGraw Hill, 1992.

7. *Process Industries Corrosion,* AICHE Symposium Series, in particular "Refinery Corrosion Overview," by J. Gutzeit.

8. G. N. Kirby, "Avoid Problems in Using a New Material of Construction," *Chemical Engineering Progress,* October, 1996, p. 71.

9. R. S. Brown, "Select Alloys for Severely Corrosive Environments," *Chemical Engineering Progress,* March 1997, p. 74.

10. P. Elliott, "Overcome the Challenge of Corrosion," *Chemical Engineering Progress,* p. 33, May, 1998.

Consensus Standards:

1. AISI: American Iron and Steel Institute
2. ANSI: American National Standards Institute
3. ASME: American Society of Mechanical Engineers
4. ASTM: American Society for Testing and Materials
5. ISO: International Organization for Standardization

Professional Associations:

NACE: National Association of Corrosion Engineers

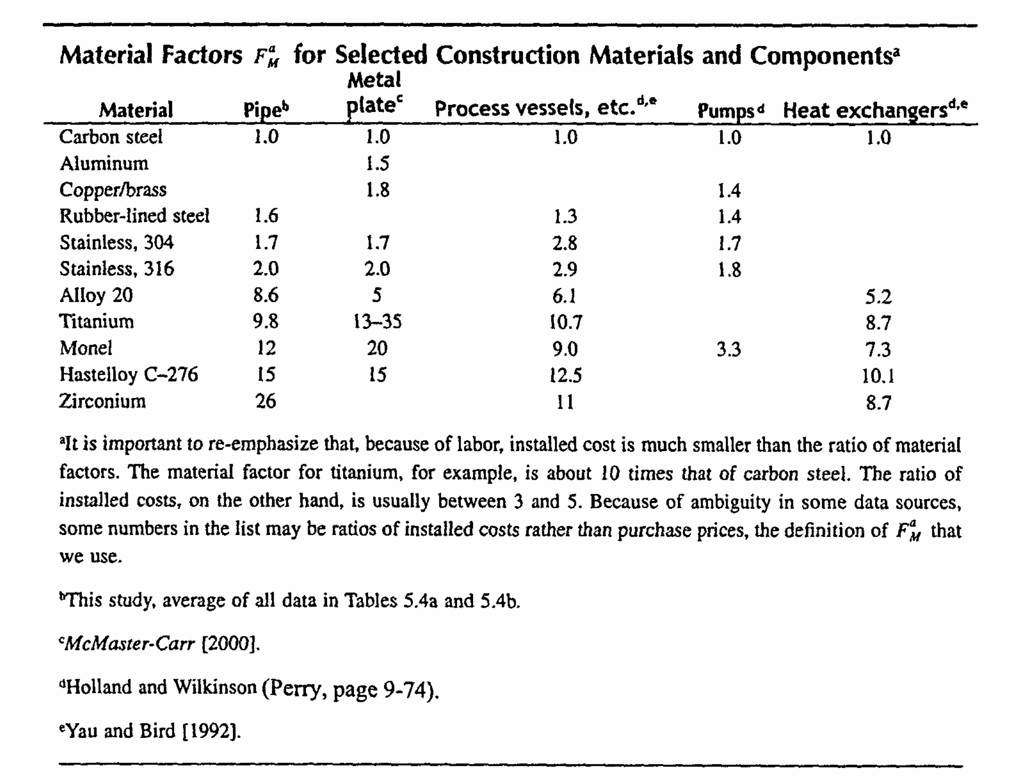
GOAL: Select correct material at lowest cost.

Materials selection based on:

1. Operating temperature
2. Operating pressure
3. Substance within process
4. External environment
5. Compatibility with other materials in process
6. Corrosion
7. Ease of fabrication, i.e. construction
8. Others

Economics impacted by:

1. Cost of raw materials
2. Installation cost
3. Service life
4. Maintenance costs
5. Repair costs
6. Downtime costs
7. Safety / environmental issues
8. Others



Material Factors F_M^a for Selected Construction Materials and Components[a]

Material	Pipe[b]	Metal plate[c]	Process vessels, etc.[d,e]	Pumps[d]	Heat exchangers[d,e]
Carbon steel	1.0	1.0	1.0	1.0	1.0
Aluminum		1.5			
Copper/brass		1.8		1.4	
Rubber-lined steel	1.6		1.3	1.4	
Stainless, 304	1.7	1.7	2.8	1.7	
Stainless, 316	2.0	2.0	2.9	1.8	
Alloy 20	8.6	5	6.1		5.2
Titanium	9.8	13–35	10.7		8.7
Monel	12	20	9.0	3.3	7.3
Hastelloy C–276	15	15	12.5		10.1
Zirconium	26		11		8.7

[a] It is important to re-emphasize that, because of labor, installed cost is much smaller than the ratio of material factors. The material factor for titanium, for example, is about 10 times that of carbon steel. The ratio of installed costs, on the other hand, is usually between 3 and 5. Because of ambiguity in some data sources, some numbers in the list may be ratios of installed costs rather than purchase prices, the definition of F_M^a that we use.

[b] This study, average of all data in Tables 5.4a and 5.4b.

[c] *McMaster-Carr* [2000].

[d] Holland and Wilkinson (Perry, page 9-74).

[e] Yau and Bird [1992].

Table from Ulrich, G. D., Vasudevan, P. T., *Chemical Engineering Process Design and Economics: A Practical Guide,* 2nd ed., Process Publishing, Durham, NH, 2004.

Piping: The pipe thickness is determined using Equation 10-92 on page 10-103 of Perry's, 7th edition. The pipe schedule is then determined from Table 10-18 in Perry's, 7th **,** knowing capacity and pressure.

Schedule 40: standard piping
Schedule 80: higher pressure
40ST: standard
40S: stainless
XS: extra strong
XX: double extra strong

For process equipment: see manufacturer's specifications for T and P.

Corrosion: Corrosion cannot be eliminated, but it can be controlled.

Types of Corrosion:

1. Uniform, i.e. steel rusting, over entire surface. Prevented by proper material selection and protection (painting)
2. Galvanic corrosion: Least noble materials corrode. Can also occur on welds.
3. Erosion: caused by jet impingement. Deteriorates pump impellers, agitator blades, pipe elbows.
4. Crevice corrosion: due to a. deficiency of oxygen, b. acidity changes, c. ion buildup, d. loss of inhibitor.
5. Pitting: surface pits lead to crevice corrosion
6. Selective leaching: one material removed from alloy.
7. Intergranular: slightly different composition at grain boundaries
8. Stress: internal or external stresses.
9. Hydrogen embrittlement: hydrogen penetrates steel to form methane.

Corrosion Rates: (1 mil = 0.001 inch)

Rate (mils/year)	**Result**
< 0.1	No corrosion
< 2	Excellent
< 20	Good
20 – 50	Satisfactory
> 50	Unsatisfactory

Types of Materials

Carbon steels (low carbon steel, mild steel) <0.25% carbon

Most commonly used material, readily welded. Suitable for most applications <u>except</u>:

- chlorinated solvents
- cold alkaline solutions
- slurries or solutions of sulfuric acid at conc. > 88%
- slurries or solutions of nitric acid at conc. > 65% at ambient T
- many others

II. **Stainless steels** - about 30 standard grades. Iron alloys with 13 to 30% chromium, 0 - 22% nickel, plus other minor agents.

Three classes:

I: martensitic
II: ferritic
III: austenitic - most common class, includes 300 series

Austenitic stainless steels: 16 - 26% chromium, 6 - 22% nickel, plus iron

Type 304: 19% chromium, 10% nickel: food, dairy, brewing.
Moderate corrosion applications

Type 316: 17% chromium, 12% nickel, 2.5% molydenum
Increased resistance to reducing conditions.

Alloy 20: 20% chromium, 25% nickel, 4% moly, 2% copper
Suitable for severe reducing conditions.

III. **Nickel alloys**

Monel (Alloy 400): 30% Cu, up to 2.5% iron, + nickel
Resistance to stress corrosion, pitting by chlorides, plus caustic alkali solutions.

Hastelloy B: 65% Ni, 28% moly, 6% iron
Resistance to reducing conditions

Hastelloy C: 54% Ni, 15% moly, 15% chromium, 5% tungsten, 5% iron.
Better resistance to oxidizing environments

Inconel (Alloy 600): 77% Ni, 15% chromium, + iron
Corrosion resistance to hot alkalies

In general, for oxidizing environments, use more chromium. For reducing environments use more nickel.

IV. **Glass**

Requires special handling and care.
Use primarily for pharmaceuticals, food, corrosives, etc.
Susceptible to erosion, mechanical shock, mechanical stress, thermal shock.

V. **Organic materials** (i.e. plastic based materials, elastomers, etc.): Most often employed as coatings and liners, but may be used as solid or reinforcing materials where conditions of temperature and pressure permit. Sometimes used for storage vessels. More fragile compared to metallic vessels, more easily punctured or fractured, cannot withstand significant thermal fluxes, nozzles are not as strong. These materials, in general, do not have as much structural strength a metallic materials.

These materials are frequently non-conductive, which can result in significant static electricity charge accumulation.

Oxidizing Agents

Dissolved sulfur
Dissolved oxygen
Nitrites
Nitrates
Peroxides
Chromates
Vanadates
Metallic cations of high oxidation state (Fe^{+++}, Cu^{++})

Reducing Agents

Hydrogen
Hydrogen sulfide
Sulfur dioxide
Hydrazine
Metallic cations of low oxidation state (Fe^{++}, Sn^{++}, Cu^{+})

Maximum Temperatures

Conventional steels: max. 600°C
High alloy or stainless steels: max. 800°C
(but strength is 1/10 of strength at room temperature!)
Above 800°C: need refractory, graphite or ceramic materials.

Minimum Temperatures (Failure due to low temperature embrittlement)

Carbon steels:	-45 °C
Stainless steels:	-255 °C