Material Selection for Chemical Process Equipment

Engr. Sandino Michael Angelo G. Aguilar, ChE

Subject Instructor

Introduction

- Any engineering design, i.e for chemical process plants/industries, is only useful when it can be translated into reality by using available materials and fabrication methods.
- Thus, selection of materials of construction combined with the appropriate techniques of fabrication can play a vital role in the success or failure of a new chemical plant or in the improvement of an existing facility

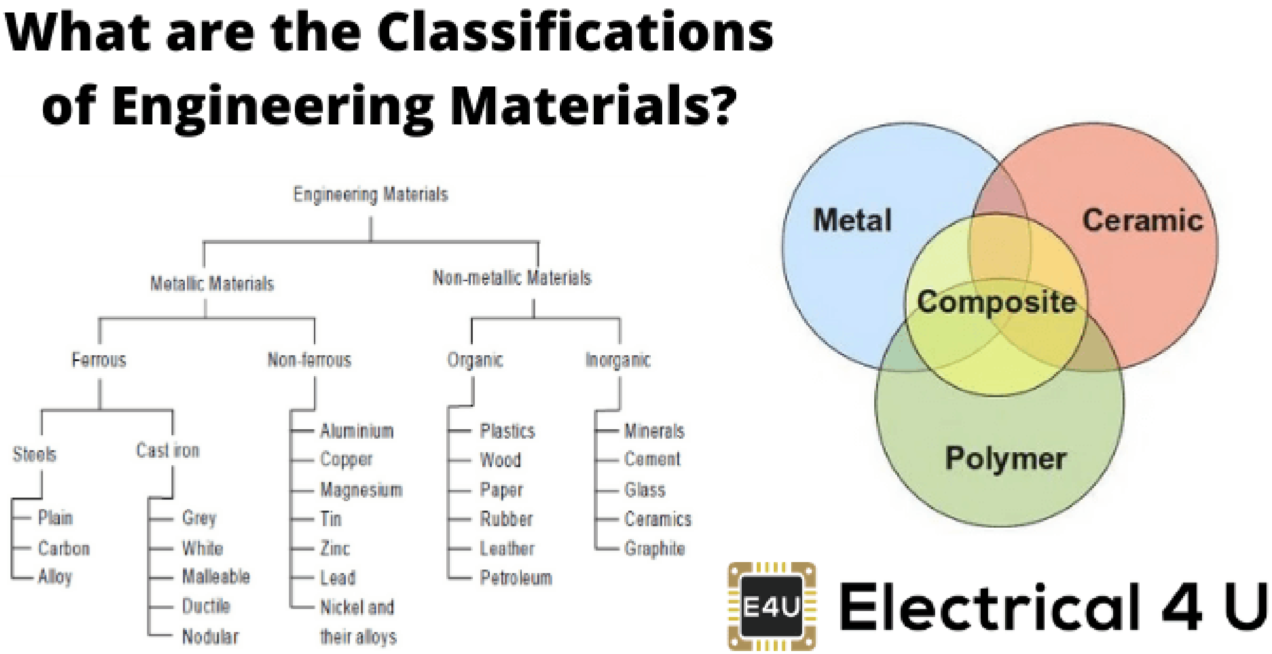
Materials of construction

- As chemical process plants turns to higher temperature and flow rates to boost yields and throughputs, selection of construction materials takes on added importance.
- Given with severe operating conditions for the plant, chemical engineers are forced to search for more dependable, more corrosion-resistant materials of construction for these process plants.
- Fortunately, a broad range of materials is now available in the market
- However, this apparent abundance of materials also complicates the task of choosing the “best” material because, in many cases, a number of alloys and plastics will have sufficient corrosion resistances for a particular application.
- Final choice cannot be based simply on choosing a suitable material but must be based on a sound economic analysis of competing materials

CLASSIFICATION OF ENGINEERING MATERIALS

Materials of construction may be divided into two general classifications:
Metals and Nonmetals.

Note: Pure metals and metallic alloys are included under the first classification



CLASSIFICATION OF ENGINEERING MATERIALS

METALS

- Polycrystalline bodies which are having number of differentially oriented fine crystals.
- Mostly solids at normal temperature (except mercury)
- High thermal and electrical conductivity.
- Have positive temperature coefficient of resistance (metal resistance increases with temperature)

Ex:

Ferrous metals – Cast iron, Wrought Iron, Steel, etc.

Non-ferrous metals – Silver, Copper, Gold, Aluminum, etc.

CLASSIFICATION OF ENGINEERING MATERIALS

NON-METAL

- Non-crystalline in nature, exists in amorphic or mesomorphic forms.
- Available in both solid and gaseous forms at normal temperature
- Bad conductor of heat and electricity
- High "resistivity" which makes them suitable for insulation purpose in electrical machines.

Ex: Plastics, rubber, leathers, Asbestos, etc.

ALLOYS

- Composition of two or more metals or metal and non-metals together
- Produces good mechanical strength, low temperature coefficient of resistance

Ex: Steels, Brass, Bronze, Gunmetal, Invar, Super Alloys, etc.

CLASSIFICATION OF ENGINEERING MATERIALS

ORGANIC MATERIALS

- All organic materials are having carbon as a common element
- Chemically combined with oxygen, hydrogen and other non-metallic substances
- Have complex chemical bonding

Ex: Plastics, PVC, Synthetic Rubbers, etc.

CERAMIC MATERIALS

- Non-metallic solids
- Made of Inorganic compounds such as Oxides, Nitrides, Silicates and Carbides.
- Posses exceptional Structural, Electrical, Magnetic, Chemical and Thermal properties

Ex: Silica, glass, Cement, concrete, garnet, MgO, CdS, ZnO, SiC, etc.

COMMONLY USED MATERIALS OF CONSTRUCTION

A. IRON AND STEEL

- these metals are not resistant to corrosion, except in certain specific environments such as sulfuric acid and caustic alkalis

- Suitable for use with organic solvents except chlorinated solvents, but traces of corrosion products may cause discoloration.

A1. Carbon steel

- most commonly used engineering material
- cheap and available in a wide range of standard forms and sizes,
- easily worked and welded.
- characterized by a high carbon content (up to 2.1% wt)
- can work under design temperature of -29 to 427 degC.

COMMONLY USED MATERIALS OF CONSTRUCTION

A2. High Silicon Irons (14-15% Si)

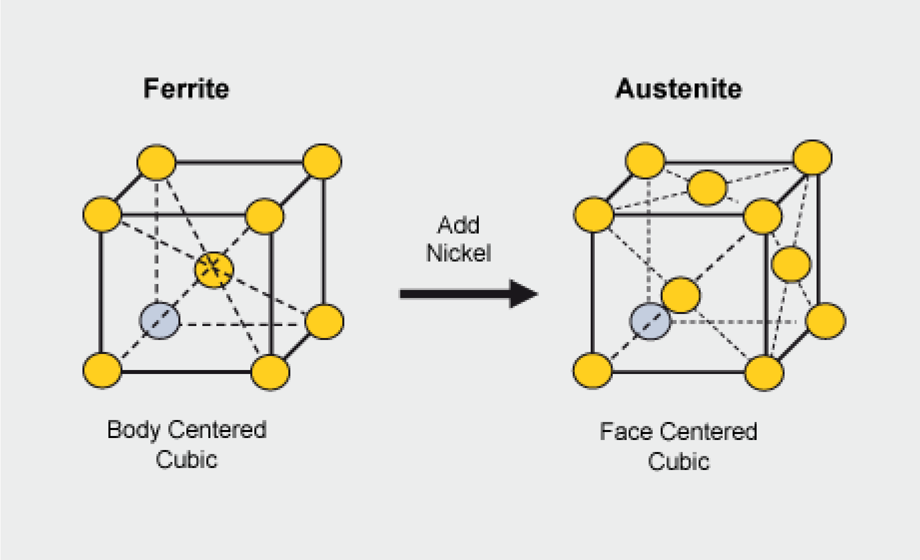
- High resistance to mineral acids, except hydrofluoric acid.
- Suitable for use with sulfuric acid at all concentrations and temperatures
- Brittle

COMMONLY USED MATERIALS OF CONSTRUCTION

B. STAINLESS STEEL

- Most frequently used corrosion-resistant materials in the chemical industry.
- Chromium content above 12% provides high corrosion resistance (higher chromium content, more resistant the alloy to corrosion in oxidizing conditions)
- Nickel is usually added to improve corrosion resistance in nonoxidizing environment.
- can work under design temperature of -257 to 538 degC.

COMMONLY USED MATERIALS OF CONSTRUCTION



B. STAINLESS STEEL

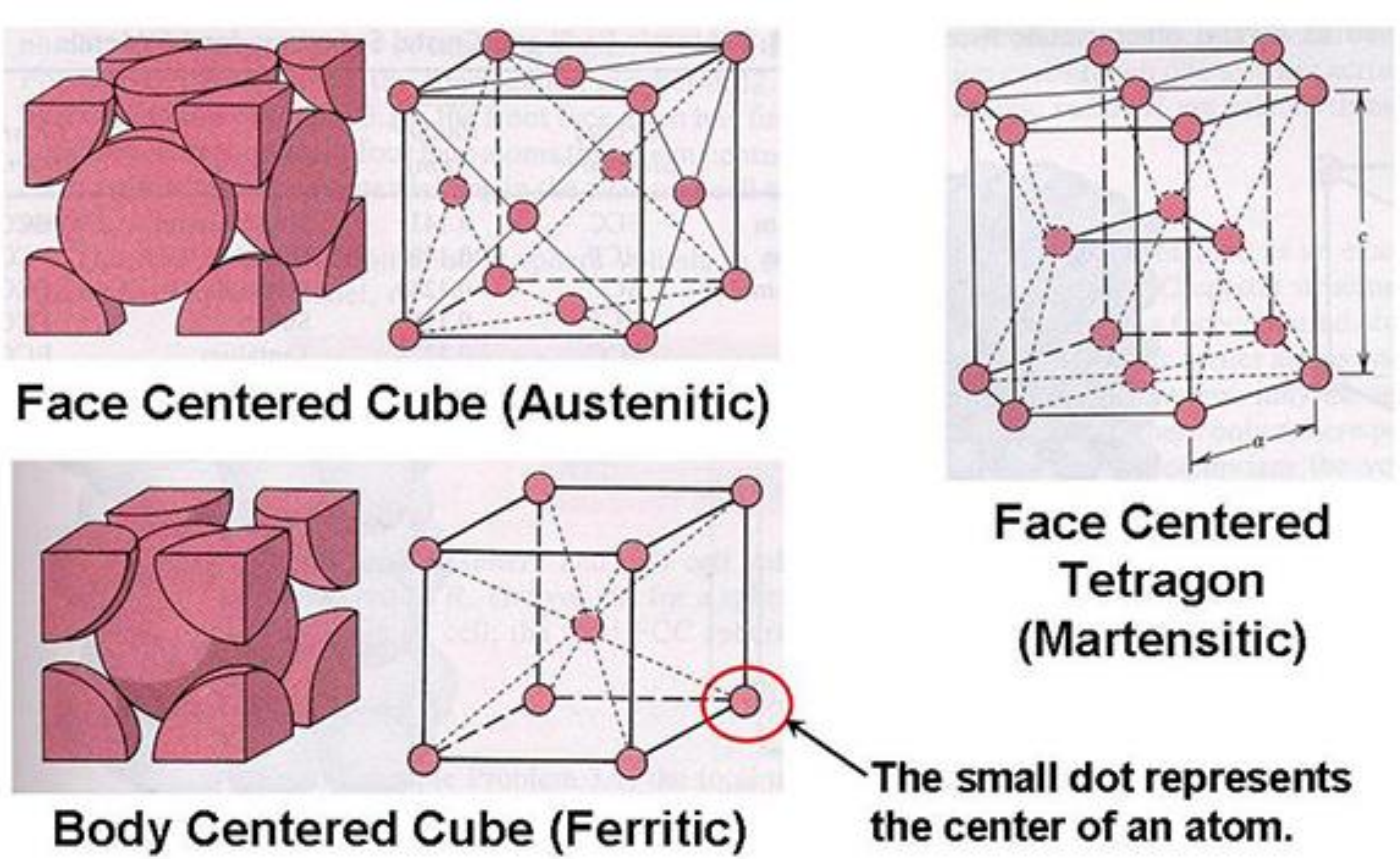
Types

1. Ferritic: 13-20% Cr, <0.1% C, with no nickel
2. Austenitic: 18-20% Cr, >7% Ni
3. Martensitic: 12-14% Cr, 0.2-0.4% C, up to 2% Ni.

- Austenitic type is the widely used type of SS in the chemical industry due to uniform structure (Face-centered cubic, with carbides in solution)

COMMONLY USED MATERIALS OF CONSTRUCTION

STAINLESS STEEL STRUCTURES



COMMONLY USED MATERIALS OF CONSTRUCTION

Common Austenitic Stainless Steel

Type 304 (18/8 SS): most generally used stainless steel. Contains minimum Cr and Ni content

Type 304L (Low carbon type of 304, <0.3% C): used for thicker welded sections, used if carbide precipitation is present with type 304.

Type 321: Stabilized version of 304 with titanium to prevent carbide precipitation during welding. Higher strength than 304L, used for high temperature systems.

Type 347: Stabilized SS with niobium

Type 316: Molybdenum is added to improve corrosion resistance in reducing conditions, such as in dilute sulfuric acid or solutions containing chlorides.

Type 316L: Low-carbon version type 316, specified if welding or heat treatment is liable to cause carbide precipitation in type 316.

Type 309/310: Alloy with high chromium content, to give higher resistance to oxidation at high temperatures.

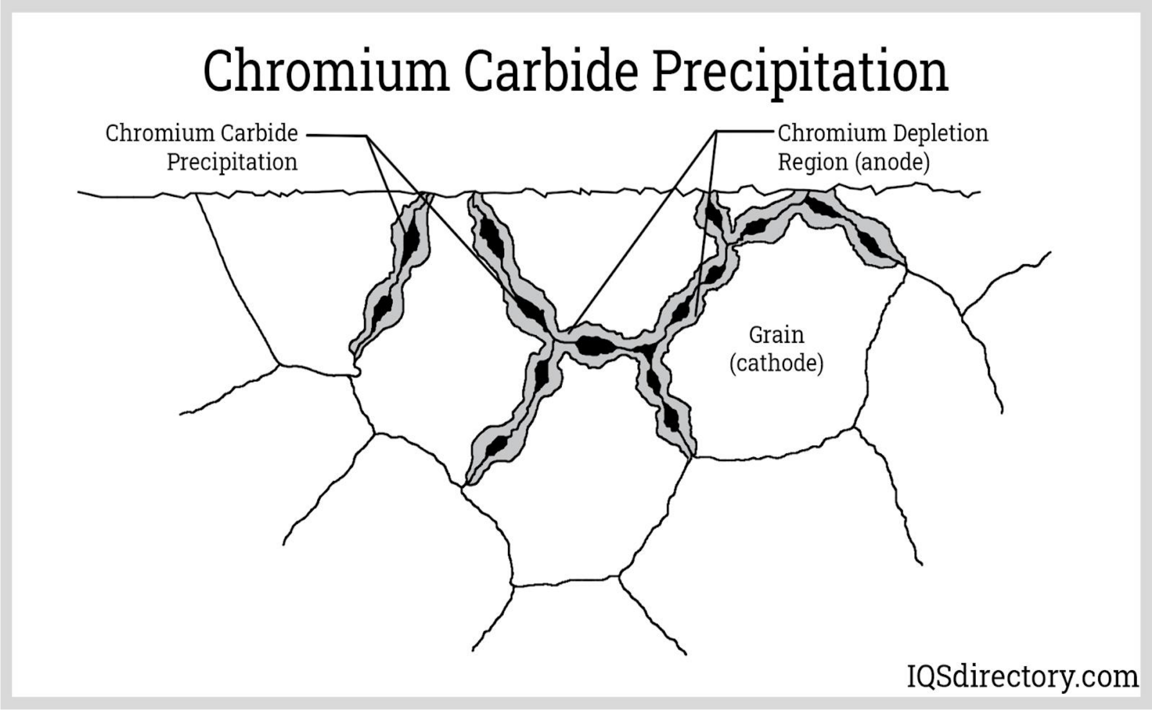
COMMONLY USED MATERIALS OF CONSTRUCTION

Table 7.6. Commonly Used grades of Austenitic Stainless Steel

Specification No./	Composition %							
AISI No.	C max	Si max	Mn max	Cr Range	Ni Range	Mo Range	Ti	Nb
304	0.08	—	2.00	17.5 20.0	8.0 11.0	—	—	—
304L	0.03	1.00	2.00	17.5 20.0	8.0 12.0	—	—	—
321	0.12	1.00	2.00	17.0 20.0	9.0 12.0	—	4 × C	—
347	0.08	1.00	2.00	17.0 20.0	9.0 13.0	—	—	10 × C
316	0.08	1.00	2.00	16.0 18.0	10.0 14.0	2.0 3.0	—	—
316L	0.03	1.0	2.0	16.0 18.0	10.0 14.0	2.0 3.0	—	—
309	0.20	—	—	22.0 24.0	12.0 15.0	—	—	—
310	0.25	—	—	24.0 26.0	19.0 22.0	—	—	—

S and P = 0.045% all grades.
AISI = American Iron and Steel Institute.

Carbide Precipitation in Stainless Steels



COMMONLY USED MATERIALS OF CONSTRUCTION

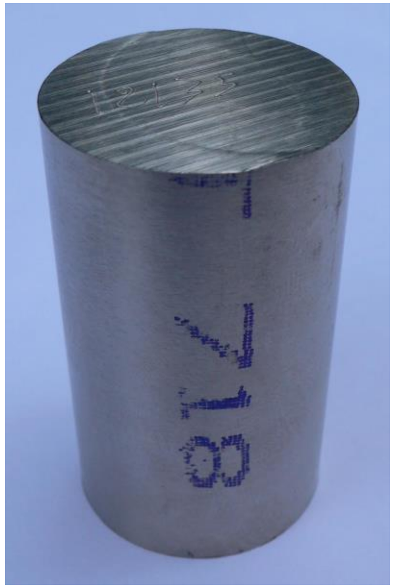
C. NICKEL (<99%)

- Nickel alloy provides good mechanical properties and is easily worked.
- Used for handling caustic alkalis.
- Not subject to corrosion cracking like stainless steel.

D. MONEL (Nickel-Copper, 2:1)

- Most commonly used alloy after stainless steel for chemical plants which provides good mechanical properties up to $500^{o}C$.
- More expensive than SS but is not susceptible to stress corrosion in chloride solutions
- Good resistance to dilute mineral acids and can be used in reducing conditions, where SS would be unstable.
- May be used for equipment handling with alkalis, organic acids, salts and sea water.

COMMONLY USED MATERIALS OF CONSTRUCTION



E. INCONEL

- Typically 76% Ni, 7% Fe, and 15% Cr in composition
- Primarily used for acid resistance at high temperatures.
- Maintains high integrity at elevated temperature and is resistant to furnace gases (if sulfur free)
- Not suitable for sulfidizing environments.

F. INCOLOY

- Nickel alloys with higher chromium content (i.e Incoloy 800, 21% Cr and RA-33, 25% Cr) are better oxidation resistance at higher temperature

COMMONLY USED MATERIALS OF CONSTRUCTION

G. LEAD

- One of the traditional materials of construction for chemical plants
- However due to high cost, it has been replaced by other materials like plastics.
- Soft, ductile material and mainly used in the form of sheets (i.e linings) or pipe.
- Good resistance to acids (i.e sulfuric acid)

H. TITANIUM

- Widely used in chemical industry particularly for its resistance to chloride solutions, including sea water and wet chlorine.
- Can be used for halide services,
- Alloying with palladium (0.15%) significantly improves the corrosion resistance, particularly to HCl

Materials of Construction for Process Equipment

Material	Maximum Temperature, °C (°F)	Typical Applications
Carbon steel (e.g., SA-285C) Cast iron (not strong) Ductile iron (stronger)	400 (750)	Cooling-tower water, boiler-feed water, steam, air, hydrocarbons, glycols, mercury, molten salts, acetone
Low alloy (Cr-Mo) steel (e.g., SA-387B)	500 (930)	Same as carbon steel, hydrogen
Stainless steels	700 (1,300)	Aqueous salt solutions, aqueous nitric acid, aqueous basic solutions, food intermediates, alcohols, ethers, freons, hydrogen, hydrogen sulfide, molten salts, molten metals
Aluminum	150 (300)	Aqueous calcium hydroxide, hydrogen, oxygen
Copper and copper alloys, aluminum bronze, brass, bronze	150 (300)	Aqueous sulfate and sulfite solutions, hydrogen, nitrogen, alcohols and other organic chemicals, cooling-tower water, boiler-feed water
Nickel-based alloys (e.g., Hastelloy, Inconel, Monel, Incoloy, Carpenter 20)	400 (750)	Aqueous nitric and organic acids, flue gases, chlorine, bromine, halogenated hydrocarbons, ammonia, sulfur dioxide, sulfur trioxide, organic solvents, brackish water, seawater
Titanium-based alloys	400 (750)	Aqueous solutions, carbon dioxide, organic solvents
Conventional plastics (polyethylene, polypropylene, ABS)	50–120 (120–250)	Aqueous solutions at near-ambient temperatures

Materials of Construction for Process Equipment

Material	Maximum Temperature, °C (°F)	Typical Applications
Fluorocarbon plastics	250 (480)	Almost everything except halogens and halogenated chemicals
Rubber lining	250 (480)	Aqueous salt solutions and aqueous basic solutions at near-ambient temperatures
Glass lining	250 (480)	Aqueous sulfuric acid solutions, almost everything except fluorine and hydrogen fluoride
Ceramics	2,000 (3,630)	Almost all aqueous solutions, except hydrogen fluoride and sodium hydroxide, at near-ambient temperatures; most gases, except fluorine and hydrogen fluoride; most solvents; water
Graphite	2,000 (3,630)	Aqueous salt and base solutions; organic solvents Cl_2, HCl, H_2, H_2S, N_2, Hg; hydrocarbons; molten salts

Selection and Evaluation: *Identification of Process Conditions*

Process design is not only on identifying chemical process equipment that will meet process performance criteria (i.e pump flow rates) but also in recommending appropriate material for the equipment based on the following:

- Process chemistry and temperature ranges
- Exposure conditions
- Design Life
- Cost
- Operations and Maintenance

Selection and Evaluation: *Benefits*

Selecting and installing appropriate and cost-effective chemical process equipment and process area materials results in the ff:

- Substantial life cycle cost savings
- Avoiding process shutdowns, fluid removal and replacement and other production impacts for replacement of equipment and systems that degrade or fail early
- Avoiding special access and safety measures for equipment/systems removal and replacement with process solutions in place
- Enhance production performance and reliability
- Reduce waste generation and conserve raw materials.
- Achieve overall energy savings

Selection and Evaluation: *Material Costs*

The quantity of a material used will depend on the material density and strength (Maximum allowable stress) and these must be taken into account when comparing material costs.

Table 7.5. Relative Cost of Metals (July 2006)

Metal	Type or Grade	Price ($/lb)	Max Allowable Stress (ksi = 1,000 psi)	Relative Cost Rating
Carbon steel	A-285	0.27	12.9	1
Austenitic stainless steel	304	0.90	20	2.2
	316	1.64	20	4
Aluminum alloy	A03560	1.27	8.6	2.4
Copper	C10400	3.34	6.7	27
Nickel	99%Ni	8.75	10	48
Incoloy	N08800	3.05	20	7.5
Monel	N04400	6.76	18.7	20
Titanium	R50250	9.62	10	27

Note: The maximum allowable stress values are at 40°C (100°F) and are taken from ASME BPV Code Sec. II Part D. The code should be consulted for values at other temperatures. Several other grades exist for most of the materials listed.

Read more on

- Materials of Construction (Towler, Sec. 7 page 397-422)

  Corrosion Allowances (Towler, Sec 13.4.6 page 984-985)

- Steel Pipes used in Process Industries (Anup Kumar Dey)

- Internet: Material Selection for Chemical Process Equipment Part 1 to 7 by Integrated Technologies, Inc.

"Good engineering work for selection and implementation of materials for chemical process equipment and systems provides significant life cycle savings plus a range of other benefits."

– Nicholas Gallerani, 2019

Integrated Technologies, Inc.

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