Process Piping Materials

Course No: M06-036

Credit: 6 PDH

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PROCESS PIPING MATERIALS

Pipe materials are selected on the basis of service requirements - most important being the strength, and the corrosion resistance (stability). In making a choice, it is necessary to know what materials are available and to what extent they are suited to the specific application. The decision is quite involved and the choice is significantly affected by the environment and the intended use. Some problems may occur because of distortion and cracking caused by thermal expansion/contraction; typically, a high-temperature alloy might change 4 inch per ft. from ambient to 1,000°C (1,832°F).

This course provides fundamental knowledge of the design and selection of process piping materials. It covers the guidance on the applicable codes and materials. It gives the pertinent information of the most common ASME/ASTM codes and material standards highlighting the applications these are suited for.

This course is the 2nd of a 9-module series that cover the entire gamut of piping engineering. All topics are introduced to the readers with no or limited background on the subject.

The course material is divided into Four (4) distinct chapters as follows:

CHAPTER -1: PIPING MATERIAL SELECTION & CHARACTERISTICS

This chapter dicusses the selection criteria for piping materials covering service life, temperature, and pressure and corrosion considerations. It presents the characteristics of piping materials required to prevent failures resulting from the environment, normal operation time exposure and upset conditions.

CHAPTER – 2: MATERIALS – METALLIC PIPING

This chapter discusses the most commonly used ASTM material designation standards for Carbon Steel, Stainless Steel, Alloy Steels, Duplex Steel, Cast Iron, Copper, Aluminium, Titanium and other materials. It gives the pertinent information of all relevant ASME/ASTM codes and standards highlighting the applications these are suited for.

CHAPTER -3: SPECIAL PIPING MATERIALS

This chapter discusses some specific considerations to piping selection for extreme high and cold temperatures. It provides specific information for hydrocarbon industry and the piping selection issues for mitigating the effects of Wet CO_2 corrosion, Hydrogen exposure, Offshore environment, Sulfides and Sulfurous Gases, Halogenation Environments, Carburizing, Nitriding, Sulfur, Amine, Caustic and Chloride environment. Other applications include the cooling water, fire water, sour water services and Microbiological Induced Corrosion (MIC).

CHAPTER – 4: MATERIALS – UNDERGROUND PIPING

This chapter discusses the piping materials for underground services, including ductile iron, concrete pipes, plastic materials such as polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), fibre reinforced plastic (FRP), reinforced polymer mortar (RPMP), polypropylene (PP), High density polyethylene (HDPE), cross-linked high-density polyethylene (PEX), polybutylene (PB), and acrylonitrile butadiene styrene (ABS).

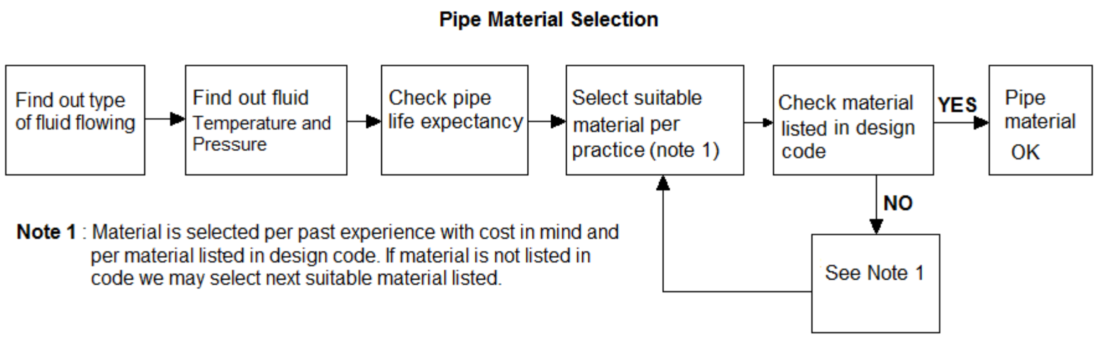
CHAPTER - 1

PIPING MATERIAL SELECTION & CHARACTERISTICS

1. Pipe Material Selection

Appropriate material selection is the cornerstone of pressure equipment and piping design. The primary objective in materials selection is the achievement of metallurgical stability to prevent failure resulting from the environment, normal operation time exposure and upset conditions. The secondary objective is the economy for achievement of the design life by the use of appropriate construction materials.

The process takes the following steps:



1.1. Selection Criteria

The material selection may involve several factors like the high strength requirements combined with high corrosion resistance of the material.

The first step is to understand the plant processes and the environmental conditions to which the plant will be subjected.

- The process information can be obtained from the Process Flow Diagrams (PFD) and Heat and Material Balance spread sheets provided by the Process Engineering Discipline.
- The environmental exposure conditions can be obtained from the basis of the design document.

Once this information is collected, a material selection philosophy is developed and discussed with the owner. When the philosophy is agreed to, the next step is to create Material Selection Diagrams (MSD). Material Selection Diagrams (MSDs) provide a summary of the process loop conditions and the selected materials of construction. Material selection is based on:

- Fluid composition. A chemical analysis of the produced fluids is generally required for the evaluation of the corrosive components as hydrogen sulfide, carbon dioxide and chlorides. Other components like scaling potential, water content, temperature profile, pressure profile and stresses on the piping and tubulars have to be considered also.
- Economic and practical considerations (purchasing, constructability, etc.) – total installed cost.
- Maximum normal operations pressure, temperature, pH, velocity, dew point, phase, and process fluid composition including contaminants.
- Start-up, shutdown, and upset conditions
- Cyclic service and steam-out operations.

The basis of material selection shall be based on:

1.1.1. Service Life

The service life is the length of time a pipe is estimated to provide adequate performance before maintenance, repair, or replacement. The following are the general guidelines to be considered while designing the systems.

- Alloy steel /stainless steel piping – 20 years' service life minimum.
- Carbon steel piping – 15 years' service life minimum.

Corrosion can cause a pipe to deteriorate and shorten its service life.

1.1.2. Code Requirements

The governing Code may depend upon the area where the unit is installed. Power generation applications may fall under the Power Piping Code (ASME B31.1), while units installed in chemical plants or refineries may be covered by the Process Piping Code (ASME B31.3).

1.1.3. Allowable Stresses

The Code sets the pressure and temperature limits for piping materials by tabulating the allowable stresses. The designer uses these stresses to determine the size and thickness of the pipe used.

1.1.4. Design Temperature

The design temperature of the fluid in the piping is generally assumed the highest temperature of the fluid in the equipment connected with the piping concerned.

Design Temperature is selected based on the Operating Temperature plus some tolerance (usually 25°F as good engineering practice) to allow for system deviation from normal operating conditions.

1.1.5. Design Pressure

The design pressure of the piping system shall be not less than the pressure at the most severe condition of coincidental internal/external pressure and temperature expected during the service life.

Design Pressure is selected based on the Operating Pressure plus some tolerance (usually 30 psi as practice) to allow for system deviation from normal operating conditions.

1.1.6. Corrosion

Corrosion is the destructive attack on a pipe by a chemical reaction with the materials and the environment surrounding the pipe.

Corrosion rates of carbon steel piping are assessed using the Langelier Saturation Index (LSI) and other published corrosion production tools. In low corrosive waters where the flow is stagnant, a 1.5 mm corrosion allowance is adequate, but 3 mm is called out for conservatism in Carbon Steel (CS) piping and equipment.

The potential for corrosion to occur, and the rate at which it will progress, is variable and dependent upon a variety of factors.

- **Hydrogen Ion Concentration (pH)**
  - Corrosion problems can occur when metal pipes are used in locations where the surrounding materials have excessive acidity or alkalinity. The relative acidity of a substance is often expressed by its pH value. The pH scale ranges from 1 to 14, with 1 representing extreme acidity, 14 representing extreme alkalinity, and 7 representing a neutral substance. The closer the pH value is to 7, the less potential the substance has for causing corrosion.

- **Soil Resistivity**
  - Corrosion is an electrolytic process. As a result, it has the greatest potential of causing damage in soils that have a relatively high ability to pass electric current. The ability of a soil to convey current is expressed as its resistivity in ohms-cm, and a soil with a low resistivity has a greater ability to conduct electricity.
  - The greater the resistivity of the soil, the less capable the soil is of conducting the electricity and the lower the corrosion potential. Resistivity values in excess of about 5000 ohm-cm are considered to present limited corrosion potential. Resistivity's below the range of 1000 to 3000 ohm-cm will usually require some level of pipe protection, depending upon the corresponding pH level (example if pH < 5.0, enhanced pipe protection may be needed for resistivity's below 3000 ohm-cm, if pH >6.5, enhanced pipe protection may not be needed unless resistivity's are below 1500 ohm-cm). As a comparative measure, resistivity of seawater is in the range of 25 ohm-cm, clay soils range from approximately 750-2000 ohm-cm. Soils that are of more granular nature exhibit even higher resistivity.
- **Chlorides**
  - Corrosion potential increases in the presence of the chloride ion. Chlorides attacks reinforced steel in concrete, if the concrete cover is inadequate for 300 series stainless steel pipes.
- **Lime**
  - Corrosion can also be caused by surrounding materials such as lime treated base, portland cement concrete and other materials. This corrosion can be prevented by isolating the pipe from its surroundings using coatings or other means.
- **Sulfates**
  - Sulfates are in abundance in Oil, Gas and Chemical plants, which combine with oxygen and water (moisture) to form sulfuric acid. High concentrations can lower the pH value and be of concern to metal pipes and even more damaging to concrete.

1.1.7. Economics

Economics is important. In many occasions, the possibility of usage of inferior materials with periodic replacement is beneficial against the usage of superior material, without sacrificing the safety of the plant.

Two methods readily available to increase corrosion resistance are lowering the carbon content of the material and reducing the instances of unprotected piping.

1.2. Characteristics of Piping Materials

The most important considerations in evaluating various pipe system materials are the strength, ductility, toughness, and corrosion resistance.

1.2.1. Strength

The strength of a material is defined by:

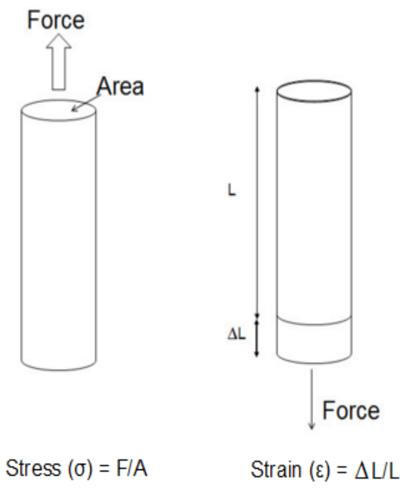
1. Modulus of elasticity
2. Yield strength
3. Ultimate tensile strength

There are two terminologies which need to be understood first.

- **Stress (σ)**
  - Stress (σ) is equal to force divided by the cross sectional area of the material (F/A).

    Stress (σ) = F/A
- **Strain (ε)**
  - Strain (ε) is a change of the material per an original length. From the definition, it equals to ∆L/L.

    Strain (ε) = ∆L/L



1.2.2. Young's Modulus (Modulus of Elasticity)

Young's modulus (the tensile modulus or elastic modulus) is a ratio of stress and strain along the axis and we can write into the following equation.

Young's modulus = Stress (σ) ÷ Strain (ε) = (F x L) ÷ (ΔL x A)

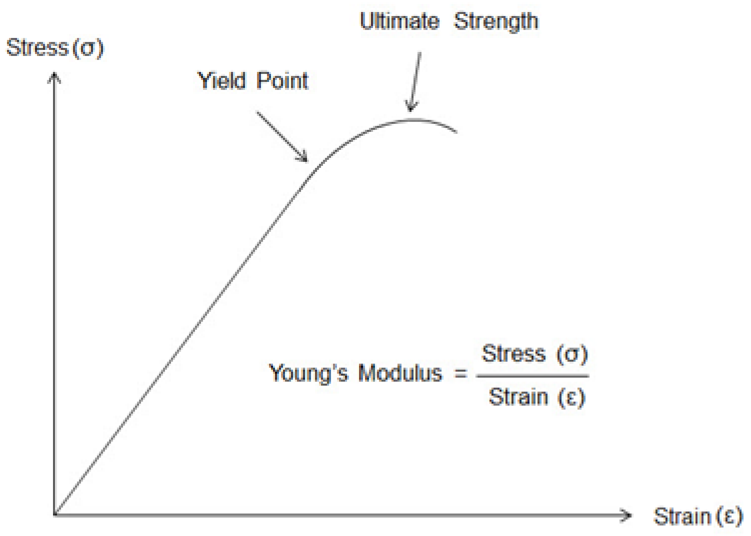
Where;

- F is pulling force.
- L is an original length of pipe.
- ΔL is an amount by which the length of the pipe changes.
- A is a cross sectional area of object.

The Young's Modulus of material represents the factor of proportionality in Hook's Law; therefore, it will be valid under the elastic zone. Young's Modulus is expressed in Pound per Square Inch (psi) in US customary unit and N/m^2 (Newton) in SI units.

1.2.3. Stress-Strain Curve

A stress-strain curve is a graph derived from Stress (σ) versus Strain (ε) for a sample of material.



STRESS - STRAIN CURVE

1.2.4. Yield Point or Yield strength

Yield Point or Yield strength is defined as the stress at which a material begins to plastically deform. Before the yield point the material will deform elastically and it will return to its original shape when the stress is released. If the tension applied is over the yield point, the deformation will be permanent and non-reversible.

1.2.5. Ultimate strength

Ultimate strength is the maximum stress applied before the material is completely parted. As the load is increased beyond the yield strength, its cross-sectional area will decrease until the point at which the material cannot handle any further load increase. The ultimate tensile strength is that load divided by the original cross-sectional area.

1.2.6. Modulus of Elasticity

Elasticity is a property by virtue of which a material deformed under the load can regain its original dimensions when unloaded. This property is utilized in piping system designs where pipes may expand or contract due to temperature differences.

Young's Modulus (modulus of elasticity)

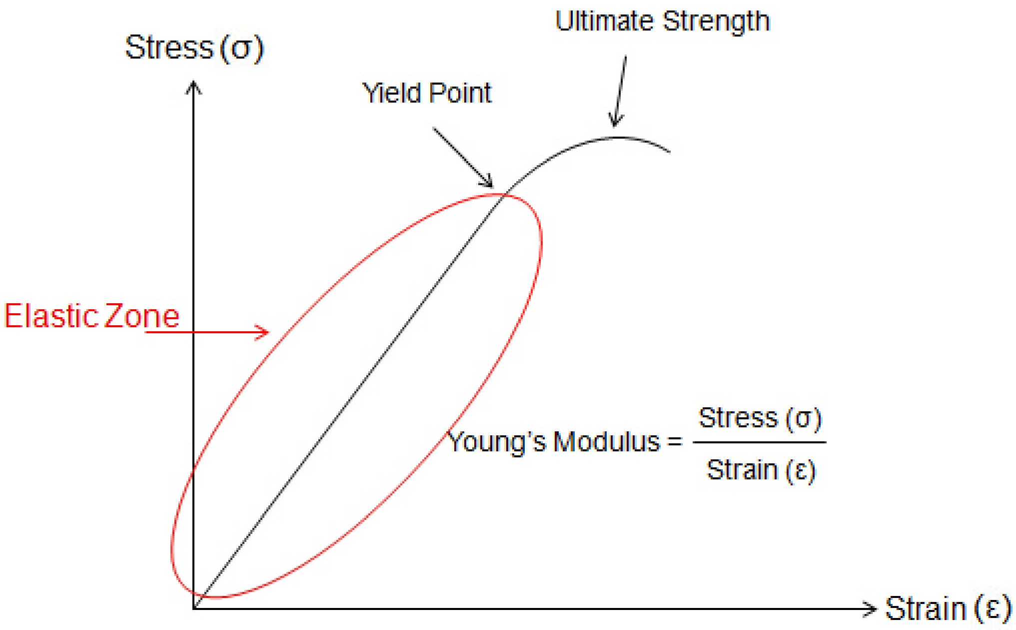
Young's Modulus (modulus of elasticity) is the slope of the Stress-Strain curve within the elastic limit (see the figure below).

Where the ratio is linear through a range of stress, the material is elastic; i.e. the material will return to its original, unstressed shape once the applied load is removed.

If the material is loaded beyond the elastic range, it will begin to deform in a plastic manner.

It means that once tensile is less than Yield Point, the Young's Modulus is valid for the calculation.

Young's Modulus of steel is 30 x 10^6 psi.



YOUNG's MODULUS IN THE ELASTIC ZONE

All of these properties are determined using ASTM standard test methods.

1.2.7. Ductility

Ductility is defined as the amount of plastic deformation that a material undergoes in resisting the fracture under stress. Ductile metals lend themselves to be formed into desired cross-sectional shapes easier and therefore are cheaper to manufacture. Ductility is commonly measured by either the elongation in a given length or by the reduction in the cross-sectional area when subjected to an applied load.

1.2.8. Malleability

Malleability is defined as the property of a metal to be deformed by **compression** without cracking or rupturing. This property is very useful for copper tubing systems, which allows the tube to be bent to follow the required route quickly without the need for expensive and time consuming fittings.

1.2.9. Hardness

Hardness is the property of being rigid and resistant to pressure; not easily scratched. It's presence in metals can be an advantage for high pressure systems but can be a disadvantage, as it can increase machining, cutting and fabrication times. It is measured on Mohs scale.

1.2.10. Brittleness

The tendency for a metal to crack or break with deformation. Metals displaying this property are not readily used for pipe or tube as this is a disadvantage to a material.

1.2.11. Toughness

Toughness is the ability of the metal to deform plastically and absorb energy in the process before fracturing. It is the indicator of how the given metal would fail at the application of stress beyond the capacity of the metal, and whether that failure will be ductile or brittle.

Steel is normally considered to be a ductile material, but under certain **low temperature** conditions, steel piping may shatter just as glass. Two common ASTM test methods used to measure toughness are the Charpy Impact and Drop-Weight tests.

1.2.12. Creep

Creep is a progressive permanent deformation of material subjected to constant stress; aka, time dependent behavior. Creep is of concern for:

- Carbon steels above ~700ºF (~370ºC)
- Stainless steels above ~950ºF (~510ºC)
- Aluminum alloys above ~300ºF (~150ºC)

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CHAPTER -2

MATERIALS – METALLIC PIPING

2. METALLIC PIPES

Metals are favored as process piping material because they offer a combination of mechanical properties that are unique and not found among non-metals.

Metals are generally strong and many can be loaded or stressed to very high levels before breaking.

2.1. Piping Material Specifications – ASME/ASTM

The most widely used standard specification for steel products in the United States is by the American Society for Testing and Materials (ASTM). It defines the specific manufacturing process of the material and defines the exact chemical composition of pipes, fittings and flanges, through percentages of the permitted quantities of carbon, magnesium, nickel, etc.

Other standard specifications are as prescribed by the American Petroleum Institute (API). The API operates similarly to the ASTM except that producers, consumers, and associations with primary interests in oil or gas are involved.

2.2. ASTM Material Designation

ASTM's designation system for metals consists of a collection of documents called material specifications for standardizing materials of large use in the industry.

- Specifications starting with "A" are for steel.
- Specifications starting with "B" are for non-ferrous alloys (bronze, brass, copper nickel alloys, aluminum alloys and so on).
- Specifications starting with "D" are for plastic material, as PVC.

Example

ASTM A105/A105M-02, Standard Specification for Carbon Steel Forgings for Piping Applications, breaks down as follows:

- **'A'** describes a ferrous metal. Prefix B is for nonferrous materials.
- **105** is a sequential number without any relationship to the metal's properties.

- **M** indicates that the standard A105M is written in rationalized SI units (the M comes from the word Metric), hence together 105/A105M includes both inch-pound and SI units.
- **02** = 2002, the year of the latest version.
- **Official title** = Standard Specification for Carbon Steel Forgings for Piping Applications.

Many of the ASTM specifications have been adopted by the American Society of Mechanical Engineers (ASME) with little or no modification. The ASME designation follows a similar scheme but uses the prefix S, for example, ASME-SA213 and ASTM A213 are identical.

2.3. Pipe Grades

Grade refers to divisions of steel (A, B, C….) within different types of pipes. It defines the mechanical properties such as the maximum tensile strengths and the yield strengths.

- **Grade A, B and C**
  - Grade A, being a softer steel, which is easier to bend.
  - Grade B has higher tensile and yield strength than Grade A. It has higher stress values and is better suited for machining operations.
  - Grade C has higher tensile and yield strength than Grades A and B.

The complete range of ASTM prefixes are A, B, C, D, E, F, G, PS, WK; however, the piping requirements referenced in ASME B31.3 call for only A, B, C, D, and E. Higher alphabet indicates higher tensile or yield strength steels, and if it is not alloyed, it has an increase in carbon content.

Example

- ASTM A 106 Grade A, Grade B, Grade C - Seamless Carbon Steel Pipe.

  In this case:
  - Grade A:0.25%C (max), 0.1% Si, 48 ksi tensile strength (min);
  - Grade B: 0.30%C (max), 0.1% Si, 60 ksi tensile strength (min);
  - Grade C 0.35%C (max), 0.1% Si, 70 ksi tensile strength (min).

Silicon (Si) is used for the deoxidizing process. Deoxidized steel is called "killed steel".

Example

Another use of ASTM grade designators is found in pipe, tube, and forging products, where the first letter P refers to pipe, T refers to tube, TP may refer to tube or pipe, and F refers to forging.

- ASTM A 335/A335-03, Grade P22; Seamless Ferritic Alloy-Steel Pipe for High Temperature Service.
- ASTM A 213/A213M-03a, Grade T22; Seamless Ferritic and Austenitic Alloy Steel Boiler, Super-Heater and Heat-Exchanger Tubes.
- ASTM A 312/A312M-03, Grade TP304; Seamless and Welded Austenitic Stainless Steel Pipe.
- ASTM A 336/A336M-03a, Class F22-Steel Forgings, Alloy, for Pressure and High-Temperature Parts.

2.4. Carbon Steel (CS) Pipes

The most commonly used material for metal piping systems is carbon steel (CS).

Carbon is present in all steels and is the principle hardening element. It raises tensile strength, hardness, resistance to wear and abrasion. CS pipes are made of a variety of grades to meet various process requirements of the industry.

- Low Carbon Steels
  - Carbon content less than 0.3%.
  - Low strength and good formability.
  - Good weldability and machinability.
  - Not responsive to heat treatment; cold working needed to improve the strength.
  - If wear is potential issue, can be carburized (diffusion hardening).
- Med Carbon Steels
  - Carbon content in the range of 0.3 – 0.6%.
  - Can be heat treated - austenitizing, quenching and tempering.

  - Medium carbon steels have low hardenability.
  - Addition of Cr, Ni, Mo improves the heat treating capacity ¬ Heat treated alloys are stronger but have lower ductility
  - Have moderate to high strength with fairly good ductility.

- High Carbon Steels
  - Carbon content 0.6 – 1.4%.
  - High C content provides high hardness and strength.
  - Hardest and least ductile.
  - Used in hardened and tempered condition.
  - Strong carbide formers like Cr, V, W are added as alloying elements to form carbides of these metals.
  - Used in applications where surface is subject to abrasion.
  - High percentage of carbon however lowers ductility, toughness and machinability.

Carbon Equivalent

- Material containing carbon more than 0.35 becomes brittle.
- Material containing carbon more than 0.43 are NOT weldable

  The Carbon Equivalent (CE) for carbon steel intended for welding SHALL NOT exceed 0.43% based on the long formula:

$$CE = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15$$

Characteristics

Carbon Steel losses all its stress resistance at 650°F/345°C. It is extremely difficult to select material at 1200°F/650°C satisfying the needs of pressure and corrosive properties of the fluid in the line.

- Tensile strength reduces at higher temperatures.
- Tensile strength of 60,000 psi reduces at 800°F/425°C to 10,800 psi at 900°F/480°C to 6,500psi and at 1000°F/540°C to 2,500 psi.
- At low temperature (< -18°F/-28°C), the material becomes brittle.
  - Low Carbon steel (LTCS) is suited for a low temperature of -46°C.

- Above 800°F/425°C, the strength decreases, pitting increases and creep decreases.
  - Alloy steels are recommended for temperatures > 800°F/425°C.
  - Poor against most acids, alkalis and salts.

Applications

- Non-corrosive piping system (fresh water, plant air, nitrogen, fuel gas, etc)
- Temperature ranges from -18°F/-28°C to around 800°F/425°C.

Standards

The most commonly used grades for piping are ASTM A106 and A53. A106 is preferred for high temperature and high pressure services.

ASTM A53:	Welded and Seamless Carbon Steel and Galvanized pipes (moderate temperatures services). Pipe furnished in the following types and grades. • Type F - Furnace Butt Welded (also known as continuous Weld) 1/8 in. to 4 in. NPS. • Type E - Electric-Resistance Welded (ERW), Grades A and B (1/8” to 24” NPS). • Type S - Seamless (SMLS), Grades A and B (1/8” to 26” NPS).
ASTM A106:	Seamless Carbon steel pipes for High Temperature Services. Suitable for bending, flanging, and similar forming operations. SMLS only Furnished in Grade A, B and C of varying strength. Grades A and B are available in most sizes and schedule numbers. Grade B permits higher carbon and manganese contents than Grade A.
ASTM A135:	Electric resistance welded (ERW) for conveying fluid, gas or vapor. ERW Only Furnished in Grade A and B.
ASTM A672:	Electric fusion welded steel pipe for high pressure service at moderate temperature services.
ASTM A333: **(Low Temp.)**	Low Temperature Service below -18°F/-28°C Seamless and welded steel pipe for low temperature services
ASTM A671: **(Low Temp.)**	Low Temperature Service below -18°F/-28°C Electric fusion welded steel pipe for atmospheric and low temperature services (sizes >=16in NB). Gr.6 is most common.

Fittings

ASTM A105:	Carbon Steel forged piping components, socket fittings, flanges, valves for ambient and moderate temperature service in pressure systems.
ASTM A216:	Steel Castings for valves, flanges, fittings or other pressure-containing parts for high-temperature service. Suitable for fusion welding. The three grades included are WCA, WCB and WCC.
ASTM A234:	Pipe fittings of Wrought Carbon Steel and Alloy Steel for moderate and elevated temperatures.
ASTM A 694:	Forging, Carbon and Alloy Steel, for Pipe Flanges, Fitting, Valves and Parts for High Pressure Transmission Service.
ASTM A420:	Low Temperature Service below -18°F/-28°C - Gr. Buttweld fittings. WPL6 is common.
ASTM A350:	Low Temperature Service below -18°F/-28°C - Forged and socket fittings**.** Gr. LF2 is common.

2.5. Killed Carbon Steel Pipes

Killed steels are defined as those, which are thoroughly deoxidized during the melting process. De-oxidation is accomplished by use of silicon, manganese and aluminum, which combine with dissolved gases, usually oxygen, during steel making. This results in cleaner, better quality steel which has fewer gas pockets and inclusions. It minimizes the possibility or extent of hydrogen blistering and hydrogen embrittlement.

- Killed carbon steel is specified:
  - Where hydrogen is a major component in the process stream.
  - Where hydrogen sulfide H_2S is present with an aqueous phase or where liquid water containing H_2S is present;
  - In process streams containing any amount of Hydrofluoric acid (HF), boron tri-fluoride (BF_3) or (BF) compounds; or where Mono-ethanolamine (MEA) and di-ethanolamine (DEA) are in solutions of greater than 5 weight percent.
  - For equipment designed for temperatures greater than 900°F (482°C) since the ASME boiler and Pressure Code does not list allowable stresses for carbon steel over 900°F (482°C).

2.6. Alloy Steel Pipes

Alloy steels are made by combining steels with one or more of other elements in total amounts between 1.0% and 50% by weight to improve its mechanical and chemical properties. Strictly speaking, every steel is an alloy, but not all steels are called "alloy steels". The simplest steels are iron (Fe) alloyed with carbon (C) (about 0.1% to 1%, depending on type). However, the term "alloy steel" is the standard term referring to steels with other alloying elements added deliberately in addition to the carbon. Common alloyants include manganese (the most common one), nickel, chromium, molybdenum, vanadium, silicon, and boron.

Alloy steels are broken down into two groups: low-alloy steels and high-alloy steels. The difference between the two is somewhat arbitrary:

- **Material Classifications**
  - **Low alloy:** are classified by smaller additions of other metals typically less than 5%. Example: 2¼% Cr – 1%Mo alloy steel.
  - **High alloy:** are classified by higher percentage of added metal usually in excess of >10%. Example: Chromium > 10.5% (stainless steel).

2.6.1. Low Alloy Steel Characteristics

- Chromium and silicon
  - An addition of up to 9% Chromium combats the tendency to oxidize at high temperatures and resists corrosion from sulfur compounds.
  - Improve hardness, abrasion resistance, corrosion resistance and resistance to oxidation.
  - Increase the hardenability and impact strength of steels.
  - Need heat treatment when welded.
  - Stainless Steels (Corrosion-Resistant Steels) – contain at least 10.5% Chromium

- Molybdenum
  - It contributes to increased high-temperature strength. An addition of about 0.5% Molybdenum greatly improves the strength of steel up to 900°F/480°C.
  - Improves resistance to reducing acids, and to pitting and crevice corrosion in aqueous chloride containing environments.
  - Increases the hardenability; enhances the creep resistance of low-alloy steels.
- Nickel
  - Increases toughness and improves low temperature properties.
  - An addition of 3 to 5% nickel will produce steels that remain tough at low temperatures up to -150°F/-100°C.
  - Improves resistance to reducing acids and caustics, and increases resistance to stress corrosion cracking particularly in chlorides and caustics.
- Chromium – Molybdenum Steel
  - Cr-Mo heat resistant steel contains 0.5-9% Cr and 0.5-1.0%Mo. Carbon content is maximum 0.20%.
  - These alloy steels are used up to maximum temperature about 1200°F/650°C.
  - Recommended for high pressure, high temperature piping in process plants.
  - Improves resistance to oxidizing corrosives and to high-temperature oxidation and sulfidation, and enhances resistance to pitting and crevice corrosion.
- Other Alloying Elements
  - Iron – Improves resistance to high-temperature carburizing environments, reduces alloy costs, and controls thermal expansion.
  - Copper – Improves resistance to reducing acids (particularly non-aerated sulfuric and hydrofluoric) and to salts. Copper additions to

nickel-chromium-molybdenumiron alloys provide improved resistance to hydrochloric, phosphoric and sulfuric acids.

- Aluminum – Improves resistance to oxidation at elevated temperatures and promotes age hardening.
- Titanium – Combines with carbon to reduce susceptibility to intergranular corrosion due to chromium carbide precipitation resulting from heat treatments, and enhances age hardening.
- Niobium (Columbium) – Combines with carbon to reduce susceptibility to intergranular corrosion due to chromium carbide precipitation resulting from heat treatments, improves resistance to pitting and crevice corrosion, and increases high temperature strength.
- Tungsten – Improves resistance to reducing acids and to localized corrosion, and enhances both strength and weldability. Nitrogen – Enhances metallurgical stability, improves pitting and crevice corrosion resistance, and increases strength.
- Cobalt – Provides increased high-temperature strength, and resistance to carburization and sulfidation.
- Manganese – strength and hardness; decreases ductility and weldability; effects hardenability of steel.
- Phosphorus – increases strength and hardness and decreases ductility and notch impact toughness of steel.
- Sulfur – decreases ductility and notch impact toughness. Weldability decreases. Found in the form of sulfide inclusions.
- Silicon – one of the principal deoxidizers used in steel making. In low-carbon steels, silicon is generally detrimental to surface quality.

These alloying elements improve machinability, wearablity, strength and corrosion resistance. Alloy metals often allow for lighter and thinner pipes.

Standards - Pipes

ASTM A335:	Seamless Ferritic Alloy Steel pipe for High Temperature Services. A 335 Gr P I / P II is used for superheated high pressure Steam Lines.
ASTM A369:	Carbon & Ferritic Alloy Steel forged and bored pipe for high temperature service
ASTM A691:	Carbon and Alloy Steel pipe (Electric Fusion Welded for High Pressure Service at High Temperature)
ASTM A333:	Low Temperature Services, Gr. 3

Fittings

ASTM A234:	High Temperature Services
ASTM A217:	Martensitic Stainless Steel and Alloy Steel castings for valves, flanges, fittings and other pressure-containing parts intended primarily for high-temperature and corrosive service.
ASTM A420:	Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low Temperature Service
ASTM A860:	Standard Specification for Wrought High Strength Low Alloy Steel Butt Welding Fittings

Forgings

ASTM A182:	High Temperature Services
ASTM A350:	Forged Carbon and Low Alloy Steel requiring Notch Toughness testing.

2.6.2. High Alloy Steel Characteristics

Steels containing 5% or more of alloying metals are generally called high alloy steels. Chromium steel and Stainless steel belongs to this category in medium temperature ranges. But at higher temperatures, a complex variety of alloy materials are used. These are discussed below.

2.7. Chromium Steel Pipes

Process chemicals with ample amounts of sulfur compounds become quite corrosive to steel at temperatures from about 550°F/290°C to 840°F/450°C. Chromium steels containing 12 to 17% chromium can very well resist these corrosive attacks.

- **Classification**

  These pipes are referred to with a P-number, such as P5, P9, P11 or P22 with corresponding weld fittings as WP5, WP9… and forged fittings with FP5, FP9… number. They are often referred to as 1 ¼ CR-1/2 moly or 21/4 CR-1/2 moly depending on the percentage of chrome and molybdenum content.

  - **P5** is resistant to hot sulfide corrosion cracking and useful from -18°F/-28°C to 1145°F/645°C. This class of alloy falls into standards of ASME/ASTM A234, A182 and A335 for piping and forgings etc. It is widely used in refineries and petrochemical plants in catalytic reformers, hydrocrackers, etc.
  - **P9 -** 9% chromium makes it more suitable to higher temperature and pressure applications, particularly in certain corrosive atmospheres. It is used in ranges from -18°F/-28°C to 1290°F/700°C in refineries and petrochemical plants.
  - **P11** is the choice of material in steam lines operated at slightly higher temperatures, where carbon cripples steel at elevated temperatures. It is used in ranges for -18°F/-28°C to 1300°F/704°C in refineries and petrochemical plants for crude distillation systems and extraction steam lines and associate piping.
  - **P22** is used at elevated temperatures for its creep strength and stress rupture properties within a typical range of -18°F/-28°C to 1090°F/590°C. It is widely used in refineries and petrochemical plants and power plants.

The main drawback of Chromium Steels is that these become brittle after extended heating cycles in 700°F – 1020°F (370°C-550°C) range.

2.8. Stainless Steel Pipes

Stainless Steel (SS) pipe and tubing are used to resist corrosion attack.

Stainless steel is not a single alloy, but a part of a large family of alloys with different properties for each member. Chromium is the principle chemical component that provides a naturally occurring protective layer of chromium oxide to resist corrosion. Stainless steel must contain at least 10.5% chromium and, the more chromium the alloy contains, the better the corrosion resistance. However, it is important to remember there is an upper limit to the amount of chromium the iron can hold.

Because of this, additional alloying elements are necessary to develop corrosion resistance to specific purposes; for example, high temperature oxidation resistance, sulfuric acid resistance, greater ductility, high temperature creep resistance, abrasion resistance, or high strength.

By definition, stainless steel must contain a minimum of 50% iron. If it contains less iron, the alloy is named for the next major element. For example, if the iron is replaced with nickel, so the iron is less than 50%, it is identified as a nickel alloy.

Alloying Elements and Their Purpose

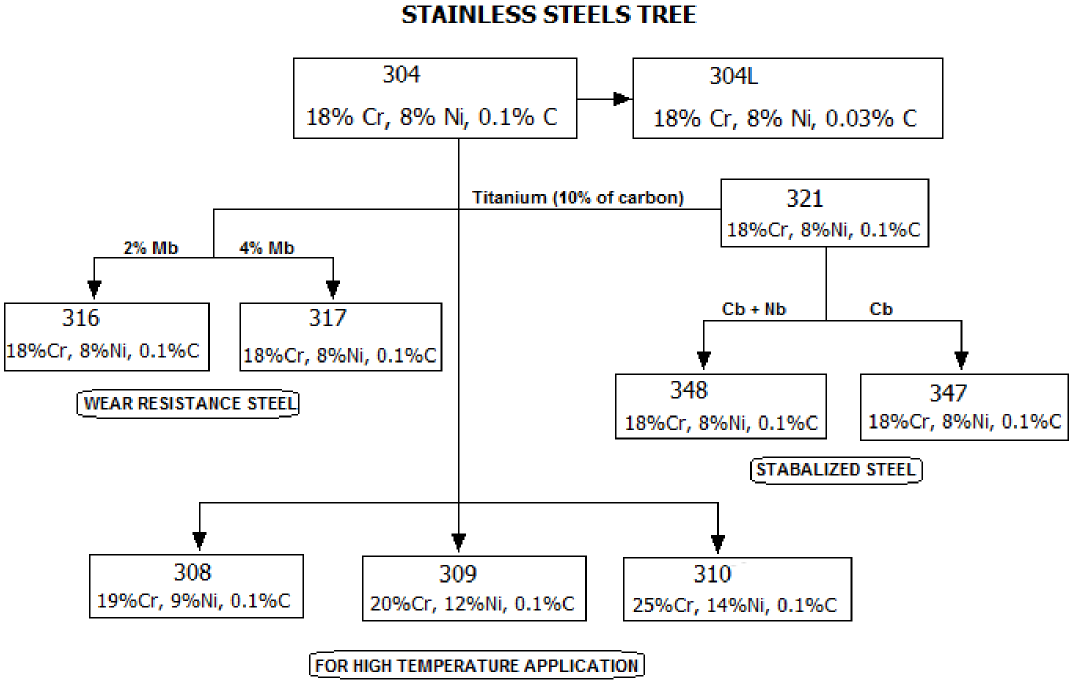
Chromium	Oxidation and Corrosion Resistance
Nickel	Austenite former - Increases resistance to mineral acids. Produces tightly adhering high temperature oxides.
Molybdenum	Increases resistance to chlorides.
Copper	Provides resistance to sulfuric acid. Precipitation hardener together with titanium and aluminum.
Manganese	Austenite former - Combines with sulfur. Increases the solubility of nitrogen
Sulfur	Austenite former - Improves resistance to chlorides. Improves weldability of certain austenitic stainless steels. Improves the machinability of certain austenitic stainless steels
Titanium	Stabilizes carbides to prevent formation of chromium carbide. Precipitation hardener.
Niobium	Carbide stabilizer. Precipitation hardener.
Aluminum	Deoxidizer - Precipitation hardener.
Carbon	Carbide former and strengthener.

2.8.1. Categories of stainless steels

There are five classes of stainless steel: austenitic, ferritic, martensitic, duplex, and precipitation hardening. They are named according to how their microstructure resembles a similar microstructure in steel. The properties of these classes differ but are essentially the same within the same class. The table below lists the metallurgical characteristics of each class of stainless steel.

Austenitic (200-300 series)	Non-magnetic and most corrosion resistant Non-hardenable by heat treatment Single phase from 0º (K) to melting point Crystallographic form – face centered cubic Very easy to weld Not subject to 885ºF (475ºC) embrittlement Not subject to ductile – brittle temperature range Not subject to hydrogen embrittlement Susceptible to chloride stress corrosion cracking
Ferritic (400 series)	Magnetic Non-hardenable by heat treatment Crystallographic form – body centered cubic (BCC) Low carbon grades easy to weld Resistant to chloride stress corrosion cracking Subject to 885ºF (475ºC) embrittlement at temperatures as low as 600ºF (315ºC) Subject to hydrogen embrittlement Subject to ductile-brittle temperature embrittlement
Duplex (Ferrite + Austenite)	Magnetic Non-hardenable by heat treatment Contains both austenite and ferrite High strength, easy to weld Subject to 885ºF (475ºC) embrittlement at temperatures as low as 600ºF (315ºC) Subject to hydrogen embrittlement Subject to ductile-brittle temperature embrittlement Resistant to chloride stress corrosion cracking if ferritic network
Martensitic (400 series)	Magnetic Heat treatable to high hardness levels Crystallographic form – distorted tetragonal Hard to impossible to weld
Precipitation Hardening	Magnetic Ultra high strength due to precipitation hardening. Crystallographic form – martensitic with micro-precipitates Heat treatable to high strength levels Weldable

The stainless steel family is quite large and specialized. There are hundreds of grades and sub grades, and each class is designed for a special application.



2.8.2. Austenitic Stainless Steels

The 200-300 series of stainless steel is known as Austenitic.

These are the most popular of the stainless steels because of their ductility, ease of working and good corrosion resistance. They are commonly called 18-8 because they are composed of 18% chromium and 8% nickel.

This type of steel is very tough and ductile in the as-welded condition; therefore, it is ideal for welding and requires no annealing under normal atmospheric conditions.

These are virtually non-magnetic and resist oxidation and corrosion of virtually all chemicals over a wide range of temperatures.

The major weakness of the austenitic stainless steels is their susceptibility to chloride stress corrosion cracking.

Key Grades

There are eighteen different grades, of which type 304L is the most widely used. The other grades are developed from the 18–8 base by adding alloying elements to provide special corrosion resistant properties or better weldability. For example, adding titanium to Type 304 makes Type 321, the workhorse of the intermediate temperature materials. Adding 2% molybdenum to Type 304 makes Type 316, which has better chloride corrosion resistance. Adding more chromium gives Type 310 the basis for high temperature applications.

- 304, 304L, 304H
- 316, 316L
- 309, 310, 317, 318, 321, 347
    - **Grade 304**
        - Grade 304 stainless is the most widely used chromium-nickel stainless for general corrosive resistant applications.
        - Low cost among all other common stainless steels for piping applications.
        - Grade 304 has a maximum carbon content of .08%.
        - Brinell hardness is approx. 160.
        - Upper temperature limit is 1400°F/760°C but is NOT recommended for use in the temperature range between 750°F/400°C due to carbide precipitation at the grain boundaries which can result in inter-granular corrosion and early failure under certain conditions.
        - SS 304 is susceptible to stress corrosion.
        - Its varieties like piping's; forgings etc. are governed by the codes ASTM A312, A376, A358, A269, A249, A403, A182 and A351.
    - **Grade 304L**
        - Type 304L is the same as 304 except that 0.03% or less (normal level is 0.08% max.) of carbon is maintained.
        - 304L provides better corrosion resistance, particularly where welding is involved, by preventing depletion of chromium at the weld zone.
        - Brinell hardness is about 140.
    - **Grade 316 and 316L**
        - Type 316 is similar to Type 304, but has a higher nickel content as well as molybdenum for stronger resistance to heat and corrosion.

- Provides better tensile, creep and stress rupture strengths at higher temperatures.
- Resists dilute sulfuric acid (1-5%) up to 122°F/50°C.
- Non hardenable and non-magnetic.
- Has superior corrosion resistance to chlorides.
- Has temperature range up to 1400°F/760°C, but is NOT recommended within the carbide precipitation range of 800 to 1650°F (425°C to 900°C).
- Brinell hardness is approx 160.
- Type 316L, like 304L, is held to a maximum carbon content of .03%. It has high resistance to chemical and salt water corrosion and is best suited for pipe assemblies with welded fittings. Brinell hardness is about 140.
- Goverened by the codes ASTM A312, G376, A358, A269, A249, A403, A182, A351, A479, A276.

Important

When using grades like 304 and 316, special attention should be paid to the carbon content. This can be as high as 0.08%, which is too high if the steel is to be welded. When choosing stainless steel for welding operations, low carbon content is crucial to prevent the formation of chromium carbide. The greater the material thickness, the longer the workpiece will take to heat during welding, and the lower the carbon content has to be.

- **Grade 317**
  - Grade 317 has excellent corrosion resistance far superior to SS316, particularly in phosphoric acid service and a host of othe critical applications such as flue gas desulfurization (FGD) systems in phama, nuclear, plastic and rubber industries .
  - Has higher tensile strengths, creep and stress rupture strength than other stainless steels.
  - 317M or 317N varieties indicate higher level of Molybdenum and Nitrogen respectively, which are effective in improving resistance

to piting and crevice corrosion at higher elevated temperatures. Nitrogen also increases the strength of these alloys.

- Governed by ASTM A312, A403, A182.

- **Grade 318**
  - Grade 318 is much more resistant to pitting than other chromium nickel alloys due to the addition of 2% to 3% molybdenum.
  - Particularly valuable wherever acids, brines, sulphur water, seawater or halogen salts are encountered.
  - Governed by ASTM A312, A403, A182.

- **Grade 309 and 310**
  - Grade 309 and 310 exhibits a lower coefficient of expansion than most of the 300 series SS.
  - Their composition is 25% Cr – 12% to 20%Ni and is used in high temperature services and tube supports in heaters.
  - High chrome and nickel allows it to be used in sulfur atmospheres.
  - These are special heat resistant austenitic stainless steels which have oxidation resistance up to about 2000°F under cyclic conditions.
  - Their creep strength is better than the others at elevated temperatures.
  - Governed by ASTM A312, A403, A182.

- **Grade 321**
  - Grade 321 is stabiliized against carbide precipitation and can operate in the severe temperatures where carbide precipitation occurs.
  - It is alloyed with titanium, which combines with carbon and nitrogen to for titanium carbide and nitrides. This leaves chromium in solution free to fight corrosion.
  - It has better high temperature creep resistance due to higher amounts of carbon (.04 – 10).

  - Goverend by ASTM A312, A403, A182, A479, A276.

- **Grade 347**
  - Grade 347 resists intergranular corrosion by eliminating carbide precipitation because of the addition of columbium.
  - Has better corrosion resistance than Grade 321 and much better resistance than Grade 304.
  - Has high temperature creep resistance due to higher amounts of carbon (.04 – 10). It is used in heat exchangers operated at higher temperatues and high temperture piping in refineries, power plants and fertilizers.
  - Can be used in high tempertaure services in continuous service at 1650°F/900°C and intermittent services at 1470°F/800°C.
  - Brinell hardness is approx 160.
  - SS347 is used in heat exchangers operated at higher temperatues and high temperture piping in refineries, power plants and fertilizers. It is good in contiuous services up to 1470 – 1650°F (800 – 900°C).
  - Goverend by ASTM A312, A403, A182, A479, A276.

Important

Alloys 310, 321 and 347 stainless steels are used in high temperature service because of their higher creep and stress rupture properties. 321 and 347 alloys have maximum temperatures of up to 1500°F/816°C for specific applications.

APPLICABLE STANDARDS

ASTM A312:	Seamless and straight seam welded Austenitic Steel pipe (Gr. TP 304/304L and Gr. TP 316/316L) intended for moderate and general corrosive service and when 8” or smaller sizes are needed.
ASTM A409:	Welded large diameter austenitic steel pipe for corrosive and high temperature services. Extra light wall thickness (schedule 5S) and light wall thickness (schedule 10S) stainless steel pipe are covered by ASTM A09.
ASTM A358:	Electric fusion welded austenitic chromium-nickel alloy steel pipe for high temperature service. Suitable for large sizes (8” and up).

Fittings

ASTM 403:	Austenitic SS Pipe fittings. Gr. WP304/304L and Gr. WP316/316L is common depending on service.
ASTM A774:	As-Welded Wrought Austenitic Stainless Steel Fittings for General Corrosive Service at Low and Moderate Temperatures.

Forgings and Socket Fittings

ASTM A182:	Forged and socket fittings. Gr. F304/304L and Gr. F316/316L is common.

2.8.3. Ferritic Stainless Steel

Until the early 1980s, these alloys were not very popular because the inherent high carbon content made them extremely brittle and imparted relatively poor corrosion resistance. Then in the late 1970s a new steel refining technique, Argon Oxygen Decarburization (AOD), was developed. This technique, together with the addition of titanium or niobium, allowed the commercial development of extremely corrosion resistant grades.

- Ferritic chromium steel contains 12% to 27% chromium and 0.08% to 0.20% carbon.
- These alloys are the straight chromium grades of stainless steel since they contain no nickel.
- Ferritic steels are magnetic and frequently used for automotive exhaust systems, decorative trim and equipment subjected to high pressures and temperatures.
- Ferritic stainless steels are resistant to chloride stress corrosion cracking, and have high strength.

Key Grades

These fall in 400 series of steel.

- Type 405, 409
- Type 430, 430Ti, 439
- Type 444, E-Brite 26-1

The most widely used ferritic stainless steel is Type 409, a 10.5% Ce alloy with no nickel. Key characteristics are:

- Grade 409 is used in services requiring abrasion and wear resistance combined with general corrosion resistance.
- It is martensitic stainless steel with superb mechanical properties.
- It is magnetic and resists corrosion and scaling up to 1200°F/ 650°C. Because of its hardness, it is best used in slurry piping and pipelines handling solids like coal.
- It can be heat treated to increase strength, hardness and wear resistance. It is not recommended in severe corrosive services.
- Brinell hardness is around 155.
- Governed by ASTM A268, A815 and A182.

2.8.4. Duplex and Super Duplex Steel

These are characterized by having both austenite and ferrite in their microstructure, hence the name Duplex Stainless Steel. Duplex stainless steels have high Chromium content (between 18 and 28%) and a narrow Nickel range (between 4 - 7%). A ferrite matrix with islands of austenite characterizes the lower nickel grades, and an austenite matrix with islands of ferrite characterizes the higher nickel range.

They are better than austenitic and ferritic steels in tensile and yield strength while offering good weldablity and formability. When the matrix is ferrite, the alloys are resistant to chloride stress corrosion cracking. When the matrix is austenitic, the alloys are sensitive to chloride stress corrosion cracking.

Key Grades

- Alloy 2205
- Carpenter 7-Mo PLUS®
- Ferralium 255, 2507

Grade 2205 is propriety material of Avesta-Sheffield used in severe conditions normally seen in high chloride environments such as bleaching plants in paper and pulp mills, and sea water and brackish water systems.

Carpenter 7-Mo PLUS,® has the best corrosion resistance against nitric acid of any of the stainless steels because of its very high chromium content and duplex structure.

Applications

- Offshore oil and gas production platforms
- FPSO
- Geothermal power
- Petrochemicals and acids
- Desalination plants
- Minerals chemical processing (nickel, copper, gold)

APPLICABLE STANDARDS

Pipes:	ASTM A790 (UNS S31803)
Fittings:	ASTM A815 UNS S31803
Forgings:	ASTM A182 Gr.F51

2.8.5. Martensitic Stainless Steels

These were the first stainless steels developed because of the inability to obtain low carbon steel. Like carbon tool steels, martensitic stainless steels derive their excellent hardness from the carbon added to the alloy. Their ability to maintain a keen edge comes from their high hardness and corrosion resistance.

Martensitic stainless steel is usually used for non-welded components such as forged parts in compressors or as seamless threaded pipe for downhole production/injection tubing. It is NOT used for welded items such as piping or vessels as it requires a lengthy 2-stage post welding heat treatment which is often inconvenient or costly.

Key Characteristics

- Martensitic chromium steel contain 12% to 18% chromium, 0.15% to 1.2% carbon, and up to 2.5% nickel.
- This group is used where high strength, corrosion resistance, and ductility are required.
- These are magnetic.

Key Grades

- Types 410, 420
- Types 440A, 440B, 440C

2.8.6. Precipitation Hardening Stainless Steel

These steels are the latest in the development of special stainless steels and represent the area where future development will most likely take place. They are somewhat soft and ductile in the solution-annealed state, but when subjected to a relatively low precipitation hardening temperature, 1000ºF (540ºC), their strength more than doubles and they become very hard. The metallurgical structure of the common grades is martensitic, but some of the special high nickel grades are austenitic.

Key Characteristics

- Magnetic
- Extremely high strength after precipitation heat treatment
- Reasonably ductile in solution annealed condition
- Corrosion resistance similar to Type 304

The primary use of precipitation hardening steels is where high strength and corrosion resistance are required. Aerospace and military applications have dominated the applications in the past, but new uses are in instrumentation and fluid control.

2.9. Cast Iron (CI) Pipes

- Carbon 2.1- 4.5 wt. % and Si (normally 1-3 wt. %).
- Lower melting point (about 300 °C lower than pure iron) due to presence of eutectic point at 1153 °C and 4.2 wt. % C.
- Low shrinkage and good fluidity and casting ability.
- May not be used under severe cyclic conditions and other services if safeguarded for heat, thermal and mechanical shock are not considered.
- May not be used in above ground flammable service above 300ºF (149ºC) or above 400 psi (2760 kPa).
- Types of cast iron: grey, white, nodular, malleable and compacted graphite.

- White iron is characterized by high compressive strength, hardness and resistance to wear because of the carbides.
- Malleable iron is white cast iron heat treated to improve higher ductility. May not be used outside -20ºF to 650ºF (-29ºC to 343ºC)
- Gray cast iron is characterized by good machinability and wear resistance because of the micro structural graphite. May not be used in flammable service above 150 psi (1035 kPa) and in other services above 400 psi (2760 kPa)
- Ductile iron develops high strength and ductility with the addition of small amounts of cesium or magnesium to grey iron. Generally limited to temperature range of -20ºF to 650ºF (-29ºC to 343ºC) and B16.42 ratings. Welding is not permitted.

APPLICABLE STANDARDS

Material Description	ASTM Standard	
Cast Steel	A216	Gr.WCA
		Gr.WCB
	A352	Gr.LCB
Cast Stainless Steel	A351	Gr.CF-8
		Gr.CF-8M
		Gr.CF-3M
	A48	Class No.30
	A126	Class B
Cast Iron	A48	Class No.35
	A126	Class C
Malleable Iron	A197	
	A47M	Gr.22010
	A47	Class 32510
Ductile Iron	A536	Gr.60-40-18
		Gr.65-45-12

2.10. Nickel and Nickel Alloys

Where Stainless Steel fails in corrosive service, alloys containing large amounts of nickel are used.

Nickel retains an austenitic, face-centered-cubic (fcc) crystal structure up to its melting point, providing freedom from ductile-to-brittle transitions and minimizing the fabrication problems that can be encountered with other metals. In the electrochemical series, nickel is more noble than iron but more active than copper. Thus, in reducing environments, nickel is more corrosion resistant than iron, but not as resistant as copper. Alloying with chromium provides resistance to oxidation thus providing a broad spectrum of alloys for optimum corrosion resistance in both reducing and oxidizing environments. Nickel-based alloys have a higher tolerance for alloying elements in solid solution than stainless steels and other iron-based alloys but maintain good metallurgical stability. These factors have prompted development of nickel-based alloys with multiple alloying additions to provide resistance to a wide variety of corrosive environments.

- **Nickel** – Provides metallurgical stability, improves thermal stability and weldability, improves resistance to reducing acids and caustics, and increases resistance to stress corrosion cracking particularly in chlorides and caustics.
- **Chromium** – Improves resistance to oxidizing corrosives and to high-temperature oxidation and sulfidation, and enhances resistance to pitting and crevice corrosion.
- **Molybdenum** – Improves resistance to reducing acids, and to pitting and crevice corrosion in aqueous chloride containing environments. It contributes to increased high-temperature strength.
- **Iron** – Improves resistance to high-temperature carburizing environments, reduces alloy costs, and controls thermal expansion.
- **Copper** – Improves resistance to reducing acids (particularly non-aerated sulfuric and hydrofluoric) and to salts. Copper additions to nickel-chromium-molybdenum-iron alloys provide improved resistance to hydrochloric, phosphoric and sulfuric acids.
- **Aluminum** – Improves resistance to oxidation at elevated temperatures and promotes age hardening.
- **Titanium** – Combines with carbon to reduce susceptibility to intergranular corrosion due to chromium carbide precipitation resulting from heat treatments, and enhances age hardening.
- **Niobium (Columbium)** – Combines with carbon to reduce susceptibility to intergranular corrosion due to chromium carbide precipitation resulting from heat treatments, improves resistance to pitting and crevice corrosion, and increases high temperature strength. Tungsten – Improves resistance to reducing acids and localized corrosion, and enhances both strength and

weldability. Nitrogen – Enhances metallurgical stability, improves pitting and crevice corrosion resistance, and increases strength.

- **Cobalt** – Provides increased high-temperature strength, and resistance to carburization and sulfidation.

Many of these alloying elements can be combined with nickel in single phase solid solutions over a broad composition range to provide alloys with useful corrosion resistance in a wide variety of environments. These alloys, in turn, provide useful engineering properties in the fully annealed condition without fear of deleterious metallurgical changes resulting from fabrication or thermal processing. Many of the high-nickel alloys can be strengthened by solid solution hardening, carbide precipitation, precipitation (age) hardening and by dispersion strengthened powder metallurgy.

Some typical examples of Nickel Alloys are Monel, Hastalloy and Inconel.

- **Monel**

Monel (also known as Alloy 400) contains 67% nickel and 30% copper. The benefits and applications include:

- High strength and excellent corrosion resistance in a range of acidic and alkaline environments and especially suitable for reducing conditions. It also has good ductility and thermal conductivity.
- Offers excellent resistance against sea water, sodium hydroxide or hydrochloric acid, fluorine, hydrofluoric acid and hydrogen fluoride.
- Corrosion resistance – coupled with strength, ductility and weldability – makes it suitable material for some of the most trying services.
- Maintains its mechanical properties from sub-zero to 1020°F /550°C. Has a maximum temperature range of 1500°F/815°C
- Effectively resists stress corrosion cracking induced by chlorides. Heat exchangers and pumps, valves and such other mechanical components in the salt water find extensive use of this material.

- Its varieties like piping and forgings are governed by the codes ASTM B165, B127, B164, B564; ASME SB 165, SB 366, SB 127, SB 164 and SB564.

- **Hastelloy**

In aggressive corrosive service, when nothing else works, many industries have traditionally turned to HASTELLOY® C-276 alloy. This alloy is a nickel – molybdenum – chromum wrought alloy that is generally considered a versatile corrosion resistant alloy by the chemical processing industries. The benefits and applications include:

- Offer extreme resistance to reducing conditions that are caused by acetic acid, phosphoric, acid, sulfuric acid and hydrogen chloride.
- Has an outstanding resistance to all kinds of corrosion (like crevice, a pittance, marine corrosion) and also have resistance to cracking caused by stress corrosion.
- Resistant to HCL at all temperatures and can even resist high concentration of the acid.
- Does not have sufficient resistance to the oxidizing environments that is found in many industries. It is also not suitable for being used in the presence of salts including cupric and ferric salts.
- Governed by ASTM B574, B575, B619, B622 and B626.

- **Incoloy**

Referred to as Nickel Alloy, Incoloy® 625 is a nickel (38- 46%) + iron (22% min.) + chromium alloy (19 - 23.5%) with small amounts of molybdenum (2.5 - 3.5%), copper (1.5 - 3%), and titanium (6-1.2%). This combination gives Incoloy 825 enhanced corrosion resistance in the harshest environments to service temperature range from cryogenic to 1800°F (982°C). Like many of the alloys in the Incoloy family, Incoloy 825 offers users a number of benefits:

- Excellent resistance to both reducing and oxidizing acids like sulfuric and phosphoric.
- Helps avoid stress-corrosion cracking.
- Stops localized attacks such as pitting and crevice corrosion.

  - High level of resistance to variety of oxidizing substances such as nitric acid, nitrates, and oxidizing salt.

- **Grade 904L**
  - 904L is a super alloy is used under severe corrosive conditions such as in dilute sulfuric acid and severe phosphoric acid applications.
  - It exhibits good resistance to pitting and crevice corrosion and intergranular corrosion.
  - It has very good resistance to stress corrosion cracking.
  - It allows easy fabrication but service temperature is limited to 840F/450C.
  - Goverened by ASTM B677, B366.

- **Alloy 20**
  - The combination of nickel, chromium, molybdenum and copper in Alloy 20 is resistive to chloride stress corrosion cracking and pitting attack.
  - It shows excellent resistance to phosphoric acid, boiling sulfuric acid at 20-40% concentration.
  - It finds extensive use in pharmaceuticals, food, paper and plastic industry.
  - It has maximum temperature range of 1400 -1500F (760 – 815C). Brinell hardness is about 160.
  - Goverened by ASTM B729, B464, B366, B473, B462.

- **Alloy 31**
  - Alloy 31 (UNS N08031) is a high alloyed stainless steel containing 31% Ni, 27 % Cr and 6.5 % Mo, which has found wide application in chemical and petrochemical process industry due to its high resistance in a variety of corrosive environments.
  - It has high resistance to localized corrosion in both acid solutions of chlorides and in seawater. Widely used the oil and gas industry.

2.11. Titanium

Titanium offers extreme resistance to corrosion of salt water and marine environment with exceptional resistance to wide range of acids, alkalis and chemicals. The corrosion resistance of Titanium is due to a stable, protective, and strongly adherent oxide film layer. This film forms instantly when a fresh surface is exposed to air or moisture. This film growth is accelerated under strong oxidizing conditions. The Titanium oxide film is capable of healing itself instantly in the presence of moisture or oxygen.

- **Characteristics**
  - Highest strength-to-weight ratio of any metal.
  - About 20 times more erosion resistant than the copper nickel alloys.
  - Excellent erosion resistance; permits use of higher pipeline velocities. Due to its high heat transfer efficiency and higher strength, thinner wall tubes can be used.
  - Commercially pure or unalloyed Titanium is available in ASTM Grades 1 through 4 and 7; grade 1 being most pure.
  - Titanium has high affinity to oxygen – strong deoxidiser.
  - Excellent corrosion resistance due to a presence of a protective thin oxide surface film. Can be used as biomaterial.
  - Can be used in elevated temperature components. It maintains corrosion resistance even at high temperatures with maximum limit at 2000°F/1095°C. Brinell hardness is about 215.
  - Limitation of pure Ti is its lower strength. Alloying is done to improve strength.
  - Can catch fire and cause severe damage.
- **Applications**
  - The corrosion resistance of Titanium in chlorine gas and chlorine containing solutions is the basis for a large amount of Titanium applications.

- Titanium resists all forms of corrosive attack in fresh and sea water to temperatures of 500°F (260°C).
- Titanium is resistant to highly oxidizing acids over a wide range of temperatures and concentrations. Here are some of the common applications in corrosion-resistant service:
  - ✓ Chlorine Chemicals
  - ✓ Hydrochloric Acid
  - ✓ Phosphoric Acid
  - ✓ Sea Water
  - ✓ Sulfuric Acid
  - ✓ Nitric Acid
- **Caution:** Although Titanium has an excellent corrosion resistance to nitric acid over a wide range of temperatures and concentrations, it should not be used in applications with red fuming nitric acid, as a dangerous pyrophoric reaction product can be produced.

- **Standards**
  - ASTM B-363

2.12. Zirconium

Zirconium Piping is very often specified for highly-corrosive industrial applications and frequently used in processes in which chlorides are a component. These and other very corrosive chemicals are damaging to lesser materials. This corrosion can rapidly lead to repair and/or replacement of the equipment in a short time frame, causing expensive and highly disruptive process stoppage.

- **Characteristics**

Zirconium is compatible with high temperatures up to 1200ºF, in reducing or oxidizing applications. In addition to high resistance to uniform corrosion attack, Zirconium can be extremely protective against pitting, stress and crevice corrosion.

- **Applications**

Some of the common service applications of Zirconium Piping include:

  - Acetic Acid
  - Citric Acid
  - Formic Acid
  - Hydrochloric Acid
  - Lactic Acid
  - Nitric Acid
  - Phosphoric Acid
  - Sulfuric Acid

- **Standards**

  - ASTM B653 PZ2

2.13. Chrome - Moly

- **Characteristics**

  - Stronger and harder than regular steel.
  - Nt as resistant to corrosion as stainless steel.
  - Best for transportation of pressurized gases.

- **Applications**

  - Power plants, fossil and nuclear.

- **Standards**

  - ASTM A199: Covers several grades of chromium-molybdenum and chromium-molybdenum-silicon seamless cold drawn intermediate alloy steel tubes for heat exchangers, condensers, and similar heat transfer apparatus. Includes sizes 1/8 in. to 3 in. inclusive in O.D.

2.14. Brass

- **Characteristics**

– Brass is a family of alloys of copper and zinc with copper content from 90 to 60% with balance zinc. Yellow brass has 66% copper and 34% zinc.

– Some brasses have small amounts of other elements such as lead, tin, antimony, arsenic or phosphorus.

– It finds various applications from potable water supply to heat exchanger piping owing to its excellent resistance to corrosion from water containing impurities.

– It shows good corrosion resistance in most environments but not recommended for acetic acid, acetylene, ammonia and salt.

– Maximum temperature limit is in the order of 500°F/260°C.

– Aluminium and silicon bronzes are more resistant to salt water than simple brass and are widely used as condenser tubing when salt water is the cooling medium.

2.15. Aluminium

- **Characteristics**

  – Aluminium has good resistance to corrosion from sulphur compounds and to atmospheric oxidation.

  – Extremely light weight and melts at 1220°F/660°C.

  – Corrosion resistance similar to SS, but it is very low strength material with a Brinell hardness of approximately 35.

  – Rarely used in industrial piping except in the certain typical service of urea. However, aluminium coated steel is used in certain equipment to save it from sulfur compounds and oxidation at high temperatures.

  – Its specific corrosion resistance characteristics make this non-toxic and it finds applications in drug, food and beverage industries.

  – Has good thermal and electrical conductivity and machining properties.

2.16. Copper

Copper has long been used for all types of domestic water services and distribution because it:

- is durable
- has good corrosion resistance
- is malleable and easy to bend
- is self-supporting
- has good flow characteristics
- requires few fittings
- can be recycled

Copper may be annealed (i.e. heated, then cooled slowly) which improves its properties, for example making it less brittle and stronger.

Although copper in general has good corrosion resistance, this depends on the environment. Acidic conditions, either from the soil (if buried) or from the water, can cause corrosion, so local pH levels should be checked before using copper pipes.

Common wall-thicknesses of copper tubing are "Type K", "Type L" and "Type M"

- **Type K**
  - Type K has the thickest wall section of the three types of pressure rated tubing and is commonly used for deep underground burial such as under sidewalks and streets, with a suitable corrosion protection coating or continuous polyethylene sleeve as required by code.
- **Type L**
  - Type L has a thinner pipe wall section, and is used in residential and commercial water supply and pressure applications.
- **Type M**
  - Type M has the thinnest wall section, and is generally suitable for condensate and other drains, but sometimes illegal for pressure applications, depending on local codes.

Types K and L are generally available in both hard drawn "sticks" and in rolls of soft annealed tubing, whereas type M is usually only available in hard drawn "sticks".

2.17. Boiler and Heater Tubes

ASTM A161:	Covers seamless, hot finished and cold drawn, low carbon and carbon-molybdenum steel still tubes, for use in carrying fluids at elevated temperatures and pressures in various types of Heaters. This specification includes tubes 2 to 9 in. O.D. Inclusive and over 0.220 in. in minimum wall thickness.
ASTM A178:	Covers electric-resistance-welded tubes made of carbon steel and intended for use as boiler tubes and super-heater flues. Includes tubes 1/2 in. to 5 in. O.D. and 0.035 to 0.320 in. minimum wall thickness.
ASTM A179:	Covers seamless cold drawn low carbon steel tubes for tubular head transfer apparatus. Includes sizes 1/8 to 3 in. O.D. inclusive.
ASTM A182:	This specification covers forged low alloy and stainless steel piping components for use in pressure systems. Included are flanges, fittings, valves and similar parts to specified dimensions or to dimensional standards such as the ANSI specifications referenced in the full ASTM Specifications.
ASTM A209:	Covers three grades of seamless carbon-molybdenum alloy steel Boiler and super-heater tubes. Includes sizes 1.2 to 5 in. in O.D. and 0.035 to 0.500 in minimum wall thickness.
ASTM A210:	Covers seamless medium carbon steel boiler tubes and boiler flues including safe ends, arch and stay tubes, and super-heater tubes. Includes sizes 1/2 to 5 in. in O.D. and 0.035 to 0.500 in. in minimum wall thickness.
ASTM A213:	This specification covers minimum-wall-thickness, seamless ferritic and austenitic steel, boiler and super-heater tubes and austenitic steel heat-exchanger tubes, designated Grades T5, TP304, etc.

Summarizing:

The table below provides the summary of frequently used ASTM Grades.

Frequently used ASTM Grades

Material	Pipes	Fittings	Flanges	Valves	Bolts & Nuts
Carbon Steel	A106 Gr A	A234 Gr WPA	A105	A216 Gr WCB	A193 Gr B7 A194 Gr 2H
	A106 Gr B	A234 Gr WPB	A105	A216 Gr WCB	
	A106 Gr C	A234 Gr WPC	A105	A216 Gr WCB	
Carbon Steel Alloy High-Temp	A335 Gr P1	A234 Gr WP1	A182 Gr F1	A217 Gr WC1	A193 Gr B7 A194 Gr 2H
	A335 Gr P11	A234 Gr WP11	A182 Gr F11	A217 Gr WC6	
	A335 Gr P12	A234 Gr WP12	A182 Gr F12	A217 Gr WC6	
	A335 Gr P22	A234 Gr WP22	A182 Gr F22	A217 Gr WC9	
	A335 Gr P5	A234 Gr WP5	A182 Gr F5	A217 Gr C5	
	A335 Gr P9	A234 Gr WP9	A182 Gr F9	A217 Gr C12	
Carbon Steel Alloy Low-Temp	A333 Gr 6	A420 Gr WPL6	A350 Gr LF2	A352 Gr LCB	A320 Gr L7 A194 Gr 7
	A333 Gr 3	A420 Gr WPL3	A350 Gr LF3	A352 Gr LC3	
Austenitic Stainless Steel	A312 Gr TP304	A403 Gr WP304	A182 Gr F304	A182 Gr F304	A193 Gr B8 A194 Gr 8
	A312 Gr TP316	A403 Gr WP316	A182 Gr F316	A182 Gr F316	
	A312 Gr TP321	A403 Gr WP321	A182 Gr F321	A182 Gr F321	
	A312 Gr TP347	A403 Gr WP347	A182 Gr F347	A182 Gr F347	

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CHAPTER - 3

SPECIAL PIPING MATERIALS

3. PIPING MATERIALS FOR SPECIAL APPLICATIONS

This chapter will discuss the piping materials for:

- High temperature service
- Low temperature service
- Corrosive and hydrocarbon service

3.1. Piping for High Temperature Service

Three primary design factors for high temperature service applications are:

- **Service life (corrosion resistance and mechanical properties)**

  Strength and service temperatures are interrelated. For a prolonged anticipated service life of say 20 years:

  – Plain carbon steels are usually limited to a maximum operating temperature of 750ºF;

  – ½ percent molybdenum alloy steels are limited to approximately 850ºF; and

  – Stainless steels can be used to considerably higher temperatures.

- **Allowable deformation**

  The rise in temperature is often associated with increased ductility and the corresponding lowering of the yield strength. The materials will overstress and fail in the elastic range. The failure in such a condition is referred to as a “creep failure” and is prevented by designing for reduced stress or temperature or by specifying a material with higher creep strength.

  – When carbon steels are exposed to temperatures greater than 775°F (413°C) for long periods, the carbide phase may convert to graphite. Graphitization causes steels to experience brittle fracture at stress levels well below their short-term rupture strength. The rupture is often inter-granular with little or no deformation of the fractured surface.

When lowered below room temperature, the propensity for brittle fracture increases.

Brittle Failure

Ductile Deformation

- **Environment**
  - Elevated temperatures tend to increase corrosive action, heat transfer may affect corrosivity, thermal cycling can increase metal wastage through spalling of protective scale on the metal surface, and metal temperature probably will not be the same as the environment to which it is exposed.

3.2. High Temperature Materials

The table below gives the approximate temperatures for different materials before the onset of creep.

Material	**Maximum Temperature**
Carbon Steel	800°F
Carbon + 1/2 Molybdenum	850°F
P11 (1¼ Cr-½ Mo) Steel	950°F
P12 (1Cr-½ Mo) Steel	950°F
P22 (2¼ Cr-1Mo) Steel	1000°F
P91 (9Cr-1Mo-V) Steel	1100°F
Type 304/304L/316/316L/321/347 Stainless Steel	1050°F
Type H Stainless Steel (304H, 316H, etc.)	1475°F
800H (Incoloy)	1750°F

3.3. Piping for Low Temperature Service (Below 32°F)

Low temperatures have an undesirable effect on ductile steels, making them more prone to brittle fracture.

Strength, ductility, toughness and other properties are changed in all metals when they are exposed to temperature near absolute zero.

Project piping standards are generally based on the industry piping standard ASME B31.3. It requires that

- Non-impact tested carbon steel can be specified for piping with a minimum design temperature of -20°F (-29°C).
- Impact-tested carbon steel shall be specified with minimum design temperatures down to -50°F (-46°).

3.4. Cold Temperature Materials

MOC's will be chosen to meet code requirements for brittle fracture mitigation. The basic materials selection philosophy used is:

- *Carbon Steel (CS)*
  - For temperatures warmer than -20°F (-29°C)
- *Low Temperature Carbon Steel (LTCS)*
  - For temperatures colder than -20°F (-29°C) but warmer than -50°F (-46°C). Impact tested CS should be specified.

  Note - Low Temperature Carbon Steel (LTCS) is defined as carbon steel that has been impact-tested at a temperature colder than -20°F (-29°C) according to the mandatory requirements of the ASME/ASTM material standards (A333, A334, A350, A352, A420). No special alloying is employed to improve low temperature impacts.
- *Austenitic Stainless Steel (Types 304 or 316)*
  - For temperatures colder than -50°F (-46°C).

    ASTM A333 grades 1, 3, 4, 6, 9 and 10 pipes are suitable for low temperature service subject to satisfying appropriate impact test requirements below -50°F.

Generally, a buried pipeline will not be subject to very low temperatures unless buried in permafrost, so no specific caution beyond the general design considerations would be required.

3.5. Stress-corrosion cracking

Stress-corrosion cracking is caused by the combined effects of tensile stress and corrosion. Many alloy systems have been known to experience stress-corrosion cracking. For example:

- Brass in ammonia
- Carbon steel in nitrate solutions
- Titanium in methanol
- Aluminum in sea water
- Gold in acetic acid
- Some stainless steels (i.e. the austenitic grades) are susceptible to stress-corrosion cracking in chloride and caustic environments.

3.6. Piping for Hydrocarbon Service

All selections shall be based per ASME code for Process pressure piping, B31.3.

- *Carbon Steel*

  The most common material used for hydrocarbon service is:

  - Sch 80, Carbon Steel (CS), ASTM A106 Gr. B Seamless Pipe or
  - API 5L Grade B Pipe
  - A672 (specific grades) electric-fusion-welded pipe may be used for sizes >16”

- *Carbon Resistant Alloys (CRA)*

  Where predicted corrosion rates for carbon steel are too high and where lining or other protection of the carbon steel is not practicable, Corrosion Resistant Alloy (CRA) materials shall be selected. Key environmental parameters influencing the corrosion properties of CRAs are:

  - Temperature
  - Chloride ion concentration

- Partial pressure CO_2
- Partial pressure H_2S
- Environment pH
- Presence of other contaminants, principally oxygen and other acidic or oxidizing contaminants.

3.7. Typical Piping Specifications for Various Hydrocarbon Services

Hydrocarbon industry operates in a severe corrosive environment and the following evaluations shall be included as minimum:

- CO_2-content
- H_2S induced sulfide stress cracking
- Chloride Induced localized pitting
- Oxygen content and other oxidizing agents
- Operating temperature and pressure
- Organic acids, pH
- Halide, metal ion and metal concentration
- Velocity, flow regime and sand production
- Biological activity
- Condensing conditions

3.7.1. Wet CO_2 Corrosion

Carbon dioxide (CO_2) environments are typical in gas treatment systems and are termed as “sweet” environments. Carbon dioxide dissolves in water to form carbonic acid. The action of carbonic acid is a general corrosion and a pitting corrosion which is more insidious and can result in a rapid perforation.

- *Carbon Steel*
  - Carbon steel (CS) may NOT be acceptable without increasing the corrosion allowance.
  - Steels with less than 0.2% carbon are most affected by carbonate SCC. Application of pH neutralizers, corrosion inhibitors, dehydrators (glycol, methanol), SS cladding, or a combination thereof, is effective in mitigating carbonic corrosion.

- *Stainless Steels*

  – Stainless steels are usually immune to wet CO_2 corrosion provided the chloride content is not too high. For temperatures exceeding 300°F duplex steels can be considered.

3.7.2. Sour Water Services

"Sour Service" refers to an environment containing Hydrogen Sulfide (H_2S).

The question of material selection in sour environments is addressed in the NACE Material Requirements document MR-01-75. It defines sour environments as fluids containing water as a liquid and hydrogen sulphide (H_2S) at a partial pressure >0.05 psi (0.0035 bar) and states that they may cause sulphide stress cracking (SSC) of susceptible steels.

Materials in the sour environment are susceptible to Sulfide Stress Cracking (SSC), Hydrogen-Induced Cracking (HIC), Hydrogen embrittlement and exfoliation (HE-HIC) that leads to various modes of failure including stepwise cracking.

H_2S in combination with water and low pH will release free hydrogen, which can be absorbed by the material and interact with the steel which becomes brittle. The key factors leading to SSC are:

- Elevated H_2S content
- Low temperatures
- Low pH
- High stress state of material (tensile stress)

When these factors are combined, a crack can initiate in the material and propagate until catastrophic failure, even when stresses are substantially inferior to the yield limit of the material. SSC is particularly critical for offshore wells where deep sea temperatures rarely exceed 4 or 5°C.

- *Recommended Materials*

  API grades L80, C90, T95 and C110 are dedicated API grades suitable for Sour Service environments. They comply with the following requirements:

  – Chemical composition

  – Grain size finer than ASTM 5

- Hardness limitation
- NACE tests (TM 0177), methods A, B or D.

- *Martensitic Steels*
  - The use of martensitic steel tubing is restricted in the presence of H_2S. Laboratory tests indicate that 13% Cr is very susceptible to SSC. As first indication its usage should be limited to pH_2S < 0.5 psi. For higher values of pH_2S, more highly alloyed tubulars are required.

- *Ferritic Steels*
  - The ferritic stainless steels give good service in H_2S and sulfide bearing process streams under a variety of conditions. Types 409, 430 and 439 have been used with good success in refineries in crude distillation, hydrodesulfurizing and hydrocracking processes. All these applications involve exposure to various sulfurous species including H_2S, polythionic acid, ammonium hydrosulfide, sulfur dioxide and others. Stress-cracking is not a problem, although numerous pitting failures have been reported after shut-downs when chloride-bearing waters were allowed to stand in the equipment. 410 SS can be used to handle sour gases at hardness' of Rc22 and below.

- *Duplex Stainless Steels*
  - Duplex stainless steels are the most common material of choice. These include 22% Cr. and 25% Cr. alternatives. Both steels are strengthened by cold working. The corrosion resistance of 25% Cr. is generally higher. As a general rule of thumb, the higher is the reduction in area, the higher is the risk for the material to crack in the presence of H_2S. Therefore the higher grades should be used with the lower pH_2S. The "Super-duplex steels" have better performance than traditional duplex and are recommended in higher pH_2S and chloride concentrations.

- *Austenitic- Nickel based Steels*
  - Nickel alloys may be susceptible to cracking in H_2S streams if sensitized or galvanically coupled to steels. High-strength nickel

alloys, whether hardened by cold-work or precipitation-hardening, become increasingly susceptible to hydrogen-induced cracking as their hardness goes up.

– In worst conditions of CO_2 plus H_2S environments, the "super austenitic" grades can provide the necessary corrosion resistance. They are Fe-base alloys and generally start with 25% to 27% Cr. and 31% Ni. They can be used up to 570°F (300°C), above 1500 psi pCO_2 and 1000 psi pH_2S. They are also resistant to SSCC in ambient temperature conditions.

– Group 4 materials are austenitic Ni-based material where nickel content ranges from 42 to 60%, while chromium content is in the range of 20-25%, and the molybdenum content starts with 3 % up to 16 %. They are used for very severe conditions.

3.7.3. Hydrogen Exposure

There are numerous examples of damage associated with hydrogen which are contained under the collective term "hydrogen damage"; sometimes also coined "hydrogen-assisted cracking" (HAC) if fracture is involved. Similar phenomena may even be known under different terms.

– Hydrogen Embrittlement and Hydrogen-Assisted Cracking/ Hydrogen Stress Cracking

– High-Temperature Hydrogen Attack on steel Decarburization

– Hydrogen Blistering or Cold Hydrogen Attack

- *Carbon Steel*

  – Carbon steel (CS) is acceptable for use in hydrogen service when operating temperatures remain below 500°F. Hydrogen attack occurs when hydrogen is contained under high partial pressure in combination with high temperatures. When the partial pressure of hydrogen is expected to be about 200 PSI, at temperatures above approximately 500°F, carbon steel is NOT recommended.

- *Alloy Steels*

  Alloy steels commonly used to resist high temperature hydrogen attacks are:

  - 1-¼ Cr – ½ Mo - (P-11)
  - 5 Cr – ½ Mo - (P-5)
  - 9 Cr-1 Mo - (P-9)
  - 16 Cr, 12 Ni, 2 Mo - (S. S 316 H)

The guide used for selecting hydrogen resistant materials is API publication 941 entitled "Steels for Hydrogen Services at elevated Temperatures and Pressures in Petroleum Refineries and Petrochemicals Plants".

3.7.4. Offshore Environment

For offshore and submarine pipeline systems a maximum corrosion allowance of 10 mm is recommended for use of CS. Otherwise corrosion resistant alloys, solid or clad or alternatively flexible pipes should be used.

Nickel 200 is susceptible to severe localized attack in stagnant or very low-velocity seawater, which can occur under fouling organisms or other deposits. For these reasons, it is NOT generally used in seawater applications, especially under conditions of impingement. In general, Nickel 200 finds application in water-cooled heat exchangers only where it is required for the process-side chemical.

In seawater or brackish water, MONEL alloys 400 and K-500 give excellent service in moderate or high-velocity systems, as do most nickel alloys. The following materials are regarded as immune to corrosion when submerged in seawater at ambient temperatures:

- Alloy 625 and other nickel alloys
- Titanium alloys
- GRP
- Other materials, provided adequately documented

3.7.5. Sulfides, Sulfurous Gases & Sulfur Environment

Sulfides and sulfurous gases are common to many applications, including fuel combustion atmospheres, petrochemical processing, gas turbines, and coal gasification. Piping systems are usually carbon steel and 5 Cr; ½ Mo with varying corrosion allowances are applied for the fluid stream containing sulfur.

- *Carbon Steel*
  - It is recognized that dry solid sulfides does not produce corrosion of carbon steel. It is only when moisture is present that sulfide induces corrosion.
  - Carbon steel generally is specified for most equipment to the 500-550°F (260-288°C) temperature range, and the corrosion allowance used is 3 mm. When the piping in this service is carbon steel and improved corrosion resistance is necessary, TP 410S stainless steel cladding is specified.
- *Nickel based Alloy Steels*
  - Mixed sulfur-and-oxygen gases can invoke very high corrosion rates typically above about 1,110°F (600°C) for nickel-based alloys, 1,688°F (920°C) for cobalt-based, and1724°F (940°C) for iron based formulations. Break away attack is commonly associated with sulfur and excess air. Once the first-formed oxide is lost or destroyed, sulfides can invade the chromium-depleted substrate, thus, causing accelerated attack to occur.
- *Stainless Steels*
  - An increase in chromium content imparts increasing resistance to high temperature sulfur corrosion.
  - Stainless steels are preferred over high-nickel alloys, because nickel is prone to forming the low-melting nickel-nickel sulfide eutectic, $Ni\text{-}Ni_3S_2$, which melts at 1,175°F (635°C). Eutectics of cobalt and iron occur at higher temperatures, 1,616°F (880°C) and 1,805°F (985°C), respectively.
  - Depending on the anticipated corrosion rates, heater tubes are usually 5 Cr – ½ Mo or 9 Cr – 1 Mo.

3.7.6. Oxidation

- *Stainless Steels*

- In noncyclic-temperature service, the oxidation resistance (or scaling resistance) of stainless steels depends on chromium content. Stainless steels with less than 18 percent chromium (ferritic grades primarily) are limited to temperatures below 1500ºF.
- Those containing 18 to 20 percent chromium are useful to temperatures of 1800ºF, while adequate resistance to scaling at temperatures up to 2000ºF requires a chromium content of at least 25 percent, such as Types 309, 310, or 446.

3.7.7. Halogenation Environments

Fluorine, the most electronegative of the elements, is also the most reactive. Its oxidizing potential is so strong that it forms compounds with all common elements, even some of the "inert" gases. Combustible substances burst into flame and even asbestos becomes incandescent when held in a stream of fluorine.

Since all metals react directly with fluorine, metals which have useful resistance depend on the formation of a protective fluoride film. At room temperature, nickel, copper, magnesium and iron form protective films and are considered satisfactory for handling fluorine at low temperatures.

- *Stainless Steels*
  - Austenitic stainless steels are severely attacked by a halogen environment at elevated temperatures. Fluorine is more corrosive than chlorine, and the upper temperature limits for dry gases are approximately 480ºF and 600ºF, respectively, for the high chromium-nickel grades. Wet chlorine gas containing 0.4 percent water is more corrosive than dry chlorine up to about 700ºF.
- *Nickel Alloys*
  - Nickel alloys are generally favored for halogen atmospheres, since iron-based alloys are more vulnerable, due to their volatile products, e.g., $FeCl_3$. Silicon additions are useful if oxidizing environments prevail, but NOT for reducing conditions.
  - At elevated temperatures, Nickel 201 and MONEL alloy 400 offer the best resistance. The most commonly used nickel alloys in processes containing fluorine are MONEL alloy 400 and INCONEL

alloys 600, 625 and C-276. Nickel 201, MONEL alloy 400 and INCONEL alloy 600 have excellent resistance to fluorine and hydrogen fluoride. At high temperatures, Nickel 201 and MONEL alloy 400 are preferred.

3.7.8. Carburizing Environments

Several environments are synonymous with carburization, including pyrolysis and gas-cracking processes, reforming plants, and heat-treating facilities that involve carbon monoxide, methane, and hydrocarbon gases. Damage is usually manifested as internal carbides, notably in grain boundaries and is generally worst above 1,050°C (1,922°F).

- *Nickel Alloys*
  - Cast iron-nickel-chromium alloys are widely used for carburizing applications, including the more recent alloys containing 1–2% silicon and 1.5% niobium (the HP Mod alloys) (4, 6).
  - High-nickel alloys (with low solubility for carbon) find many applications for carburizing conditions.
  - Stronger nickel-based alloys with high chromium and silicon contents are useful in more demanding environments.
- *Stainless Steels*
  - Highly alloyed ferritic stainless steels (that are able to more rapidly form a thin oxide film) tend to outperform austenitic steels.

3.7.9. Nitriding

Relatively little is reported about Nitrides other than material performance is weakened leading to embrittlement. It is common to expect damage with nitrides at 700–900°C (1,290–1,650°F). Iron tends to be detrimental, as do aluminum and titanium in low concentrations. Silicon forms a brittle intermetallic compound with nitrogen and can contribute to scale spallation, especially in applications at low oxygen concentrations (potentials), where thin oxides can form, and during thermal cycling.

- *Nickel Alloys*
  - Nickel- and cobalt-rich alloys effectively resists nitride attack, because of the low solubility of nitrogen in these base metals.
- *Coatings*
  - High-temperature coatings or surface modifications are generally based on chromium, aluminum, or silicon, which, at high temperatures, form protective oxides rich in chromia, alumina, or silica, respectively. In more recent years, there have been developments in applying so-called alloy coatings, for example, the use of MCRALY (metal, chromium, aluminum, and yttrium) on steels or other high-temperature alloy substrates.

3.7.10. Amine Environment

Amine units are widely used in upstream oil and gas applications and in refineries for removing CO_2, H_2S and related constituents from hydrocarbon gas streams. Both lean amine and rich amine pose corrosive issues. Stress Corrosion Cracking (SCC) and general corrosion are the potential degradation mechanisms. Proprietary amine solvents are used to remove acid gas (CO_2) from the incoming process feed stream. These amine solvents charged with the acid gases are corrosive. Factors that influence corrosiveness include the type of amine, solution strength, acid gas composition, acid gas loading, temperature, velocity, organic acids and the presence of heat-stable salts (HSAS). Oxygen contamination of the amine during storage and processing can lead to the formation of organic acids such as formic, acetic, etc.

- *Carbon Steel*
  - In refinery service, carbon steel is generally the main material of construction for the LEAN amine piping, and absorber, stripper and reboiler vessels.
  - Carbon or low-alloy steels are subject to Stress Corrosion Cracking (SCC) when in contact with RICH amine solutions above approximately 4% by weight. This type of caustic cracking is also commonly referred to as caustic embrittlement.
  - For all carbon steel piping in amine service, PWHT (stress relieving) shall be performed at 1275°F ± 25°F (691°C ±14°C) after welding or forming operations to mitigate caustic cracking.

- Several factors can limit the use of carbon steel, including: the formation of organic acids; high acid gas loadings; corrosive contaminants; erosion and/or high velocities; and high temperatures. Process control is critical in avoiding corrosion problems in amine systems, including limiting heat-stable salt loadings, filtering out solids and controlling temperatures and pH.

- *Stainless Steels*
  - Austenitic stainless steels are typically used for higher temperature equipment such as the reboiler tube-sheet and tubes, stripper overheads, hot rich amine piping and lean/rich heat exchangers, and often more widely in the reboiler. Stainless steels are often also used for vessel internals and pumps. The main grades used are 304/304L and 316/316L: higher alloy stainless steels or other CRAs are used relatively rarely in refinery applications.
  - Austenitic 300 series SS piping shall be specified with a 1/64 in (0.4 mm) Corrosion Allowance (CA) in rich amine service. The fluid velocity limit for 300 series SS is 4 meters per second.

Materials which are NOT suitable for amine service include martensitic stainless steels (12Cr, AISI 410 etc.), aluminum and copper-based alloys.

For additional guidance for avoidance of corrosion of stress corrosion cracking (SCC) refer to API 945.

3.7.11. Caustic Environment

Corrosion rates in chemical processing media usually decrease as the pH increases. In alkaline solutions such as Caustic, the hydrogen ion is present in very low concentrations. However, many metals pass through a minimum corrosion rate at some pH, usually basic, and then suffer increased corrosion as pH continues to rise. Quite often corrosion by alkalies leads to pitting and another localized attack because they tend to form cathodic films, and the attack is concentrated at susceptible anodic areas. Austenitic stainless steels and other low nickel materials may suffer either stress-corrosion cracking or general corrosion in hot concentrated caustic.

Crevice corrosion is a concern when local high caustic concentrations are produced as a result of heating and/or solution evaporation. For this reason, care in design of heat transfer equipment (avoiding crevices) is advisable.

- Caustic cracking of highly stressed (e.g., as-welded or as-bent) CS is not anticipated when exposed to caustic solutions up to 50% weight, at temperatures below 115°F (46°C).
- In the 115 to 180°F (46 to 82°C) temperature range, cracking is a function of the caustic concentration.
- Above 180°F (82°C), cracking is highly likely for all concentrations above about 4% wt.

- *Carbon Steel*
  - Carbon steel is the material of choice for handling caustic solutions at low temperatures. At higher temperature and even at ambient temperature but caustic concentrations above 50%, it becomes very corrosive.
- *Stainless Steels*
  - 300 series SS are NOT recommended for caustic service because they offer little advantage over CS. Their corrosion resistance is only marginally better, and they are also subject to caustic cracking above approximately 110°C (230°F).
- *Nickel Alloys*
  - Nickel base alloys offer the best resistance to SCC in caustic solutions at concentrations up to 70%. NACE SP0403 offers guidance in determining the need for PWHT or Nickel Alloys in caustic environments.
  - In caustic of 70% concentration or more, even the high-nickel alloys will crack over proedelonged periods of time at temperatures above 300°C and at high stress levels. In ascending order of merit are Alloy 400, Alloy 600, Alloy 200 and Alloy 201.
    - Alloy 400 can suffer SCC at concentrations in excess of 80% if temperatures exceed 175°C.
    - Alloy 600 is more readily cracked by hot concentrated caustic when oxygen is present.
    - Nickel Alloy 200 fails under very high stress at temperatures above 300°C after prolonged periods.

3.7.12. Corrosion by Acids

Acids can be either oxidizing or reducing in nature. Some metals are resistant to oxidizing acids (e.g. nitric) while others are resistant to reducing acids (e.g. hydrochloric or sulfuric). By alloying such metals it is possible to produce materials that resist corrosion in both media.

The choice of an alloy for a specific environment will depend on the acid or the mixture of acids present, on concentration, temperature, aeration, contaminants, flow characteristics, the presence and tightness of crevices, other material in the system, and many other environmental conditions.

- **Sulfuric acid:** The most commonly used nickel alloys in processes containing dilute sulfuric acid are INCOLOY alloys 25-6MO, 825 and 020, and INCONEL alloy G-3. For aggressive, hot, sulfuric acid environments, INCONEL alloys 625, 622, C-276 and 686 are most often selected.
- **Hydrochloric acid:** The high-nickel alloys are among the few metallic materials with useful resistance to hydrochloric acid solutions. The presence of oxidizing contaminants (e.g. ferric or cupric ions) can drastically change the corrosivity and corrosive characteristics of a hydrochloric acid environment and the presence of such species must be considered in material selection. The most commonly used nickel alloys in processes containing dilute hydrochloric acid are INCOLOY alloys 25-6MO, 825 and 020, and INCONEL alloy G-3. For aggressive, hot hydrochloric acid environments, INCONEL alloys 625, 622, C-276 and 686 are more often selected.
- **Hydrofluoric Acid:** The choice of a material for handling hydrofluoric acid should be based on the concentration, temperature, velocity and degree of aeration of the acid, and on the presence of impurities. As with other non-oxidizing acids, aeration or the presence of oxidizing chemicals in hydrofluoric acid increases its corrosive attack on most metals. The most commonly used nickel alloy in processes containing hydrofluoric acid is MONEL alloy 400. Nickel 200 and INCONEL alloy 600 are used for some applications.
- **Phosphoric Acid:** Pure phosphoric acid has no effective oxidizing power and is classified as a non-oxidizing acid, much like dilute sulfuric. Commercial phosphoric acid, however, usually contains impurities such as fluorides and chlorides that markedly increase its corrosivity. The most commonly used nickel alloys in processes containing pure phosphoric acid are INCOLOY

alloys 825, 020 and 25-6MO, and INCONEL alloy G-3. For aggressive, hot phosphoric acid environments, especially those contaminated with halides, INCONEL alloys 625, 622, C-276 and 686 are selected.

- **Nitric Acid:** Nitric acid is a strongly oxidizing and, because of this, alloys with the best resistance are those that form passive oxide films. Thus, alloys with significant chromium contents offer much greater resistance than those with lesser amounts. While nickel alloys offer good resistance to pure nitric acid, they are particularly effective in mixed acid media (e.g. nitric with reducing acids such as sulfuric or phosphoric). When small amounts of chlorides or fluorides are present, Ni-Cr-Mo alloys show superior resistance.

3.7.13. Corrosion by Salts

When dissolved in water, salts increase their conductivity and thereby are able to carry higher corrosion currents. Therefore, galvanic effects are more pronounced in salt solutions than in pure water. Salts may be categorized and their corrosive characteristics defined in table below:

Characteristic pH	Halide	Non-halide
Neutral	Sodium chloride Potassium chloride	Sodium sulfate Potassium sulfate
Neutral and Alkaline-Oxidizing	Sodium hypochlorite Calcium hypochlorite	Sodium nitrate Sodium nitrite Potassium permanganate
Acid	Magnesium chloride	Potassium bisulfate Ammonium sulfate Aluminum sulfate
Acid-Oxidizing	Cupric, ferric, mercuric, stannic chloride	Cupric, ferric, mercuric, nitrate, or sulfate
Alkaline	Potassium fluoride	Sodium and potassium phosphates, carbonates

The most commonly used nickel alloys in process environments containing sulfate salts are INCOLOY alloys 25-6MO, 825 and 020 and INCONEL alloys G-3, 625, 622, C-276 and 686. For processes using chloride salts, the most commonly used materials are MONEL alloy 400 (for reducing conditions), INCOLOY alloys 25-6MO, 825 and 020, and INCONEL alloys G-3, 625, 622, C-276 and 686.

3.7.14. Chloride Environment

Dry chlorine is not particularly corrosive at ambient temperatures. Chlorine gas reacts with the water to form equal parts of hypochlorous and hydrochloric acid. Hypochlorous acid is an oxidizing acid and bleaching agent which is reduced to hydrochloric acid in the bleaching reaction. This combination of an oxidizing and a non-oxidizing acid is responsible for the corrosive effect of moist chlorine on metals.

Chloride corrosion can be severe in an acidic solution with a pH ≤ 4.5.

- *Stainless Steels*
  - The 300 series SS are susceptible to pitting and under deposit corrosion in chloride containing solutions. However, the most significant threat is from chloride induced-stress corrosion cracking (Cl-SCC) when the operating temperature is above the threshold temperature for SCC. To reduce the potential for pitting and Cl-SCC, the following precautions are recommended for 300 series SS.
  - 304L/316L series SS materials (e.g., plates, piping, forgings, fittings, etc.) are typically specified to be supplied in the solution annealed condition in order to minimize residual stresses that can contribute to CI-SCC.
  - Bulk 300 series SS piping components are generally externally coated and provided with end caps/plugs as an added precaution against pitting during transport and storage. During transport, piping will be shipped and stored inside in a closed dry environment wherever possible. Deck mounted equipment, pipe and components should be avoided for ocean shipment.
  - Hydrostatic testing water quality should be controlled to reduce chloride concentration to an acceptable level. Chloride levels should be 50 mg/l for austenitic stainless steel and 100 mg/l for carbon steel.
  - Introduction of chlorides into the process system is mitigated by the use of demineralized water for absorber tower washing and solvent make-up.

- *Nickel Alloys*
  - Nickel alloys are outstanding in their resistance to chlorine and hydrogen chloride at elevated temperatures. Although chlorine is a strong oxidizer and will combine directly with metals, at lower temperatures this reaction is so sluggish that dry chlorine can be shipped in steel. As the temperature is increased, this reaction rate increases slowly until a critical point (which varies with the metal under consideration) is reached.
  - MONEL alloy 400 is a standard material for trim on chlorine cylinder and tank car valves, for orifice plates in chlorine pipe lines, and for various parts of chlorine dispensing equipment. Wet chlorine at temperatures below the dew point, or aqueous solutions containing considerable amounts of free chlorine, are very corrosive to all of these alloys, except INCONEL alloy C-276 which is used for valve stems in MONEL alloy 400-seated valves to combat the effects of the ingress of moisture.

3.7.15. Water Corrosion

Corrosion rates of carbon steel piping are assessed using the Langelier Saturation Index (LSI) and other published corrosion production tools. In low corrosive waters where the flow is stagnant, a 1.5 mm corrosion allowance is adequate but 3 mm is called out for conservatism in CS piping and equipment.

For higher corrosive waters, corrosion assessment will consider temperature, oxygen concentration, halide concentration, and other pertinent factors.

Underground piping may be non-metallic. Corrosion of underground water piping will be mitigated by use of HDPE.

Demineralized water is corrosive to CS.

Above ground piping will be fabricated from 304L SS (or 316L SS), no corrosion allowance will be added.

3.7.16. Microbiological Induced Corrosion (MIC)

MIC is a form of corrosion caused by living bacterial. It is often associated with the presence of tubercles or slimy biofilms. MIC Corrosion is usually observed as localized pitting, sometimes under deposits or as tubercles that shield the organisms.

In CS, damage is often characterized by cup-shaped pits within pits and in austenitic stainless steel as subsurface cavities. Critical Factors to be considered with MIC include:

- Velocity – stagnant or low-flow conditions
- Temperature
- Oxygen Concentration
- Nutrients including inorganic substances (e.g. sulphur, ammonia, H2S) and organic substances (e.g. hydrocarbons, organic acids). In addition, all organisms require a source of carbon, nitrogen, and phosphorous for growth.

MIC has been found in heat exchangers, in the bottom of water storage tanks, piping with stagnant or low flow, and in piping in contact with some soils. Using well or ground water is especially susceptible to MIC contamination.

- Appropriate material selection, coating, chemical treatment (chlorine, bromine, ozone, ultraviolet light, or proprietary compounds) should be considered to minimize MIC.
- Bleach (NaOCl) is an effective biocide but must be used in the correct concentration (2 mg/l) to preclude damage to the MOC.
- A project hydrotest water quality specification should be issued for use during fabrication and construction, especially during hydrostatic tightness testing of equipment and piping.
- One of the most important steps is removal of water from equipment and equipment immediately after the hydro test followed by proper drying, preservation and capping.
- Using dry, oil free compressed air with a dew point of -40°F (-40°C) has been proven to be effective.

3.8. Applications for Cooling Water and Fire Water Systems

In Refineries, frequent failures have been experienced in cooling water and fire water services especially in the form of seam opening in ERW pipes.

It is recommended to use API 5L Gr. B standard pipes due to its mandatory requirement of NDT. The testing ensures improved weld quality and documentary evidence of Hydro test.

For lower diameter pipes (up to 6” in diameter), seamless pipes are recommended considering lower thickness in this range, which are detrimental in case of any weld deficiencies.

ERW/EFSW (Electric resistance welded/Electro-fusion seam welded) 8” to 14” pipes confirming to API 5L Gr. B are recommended for improved quality of ERW welding. For diameter 16” and above, EFSW pipes are recommended considering the superior welding quality. The recommended pipe specifications for Cooling Water and Fire Water services of different diameters are given below:

Up to 6”	Seamless Pipes Of A 106 Gr. B Or API 5L Gr. B Standards
8” to 14”	ERW/ EFSW pipes of API 5L Gr. B Standard
16” and above	EFSW pipes as per API 5L Gr. B Standard

3.9. Measures for Corrosion Protection

Corrosion is the destructive attack on a pipe by a chemical reaction with the materials and environment surrounding the pipe. The corrosion protection measures include:

- Selecting the corrosion resistant pipe material or using a coated pipe. Stainless steel exhibits good characteristics against corrosion. In extreme corrosive environments, special materials and alloys such as Titanium, Monel, Hastelloy, Incloy etc., are often recommended.
- Selecting a pipe with an adequate corrosion allowance and wall thickness.
- External coating of pipe against atmospheric corrosion.
- Cathodic protection of the pipe, with either live current or the installation of sacrificial anodes such as zinc bars.
- Installation of an oversize conduit with the intent that it will be relined at a later date after corrosion damage occurs.

3.9.1. External Corrosion Protection

- For protection against atmospheric corrosion, the piping that operates at a temperature of 250°F (250°C) or less and is not insulated can be protected by either a three coat paint system such as inorganic zinc primer, epoxy intermediate coat plus aliphatic polyurethane topcoat or hot tip galvanizing. Some projects select a two coat system which consists of a coat of zinc rich epoxy plus a polyurethane topcoat. Heat resistant topcoats such as silicone acrylic or heat cure silicones are used for higher operating temperatures up to the melting point of zinc.

- Inorganic zinc coatings are NOT typically used under insulation, as zinc coatings exposed to water, at temperatures above 150°F (66°C) become passivated, which can result in the coating becoming a cathode to the steel, resulting in the preferential corrosion of the steel substrate. Where insulation is required, the inorganic zinc coating should be covered with an additional epoxy coating.
- Good practice is to procure bulk carbon steel piping with an inorganic zinc primer. The primer can then be top coated in the field with most high performance coating systems where the operating temperature is below the melting point of zinc 750°F (400°C). Insulated equipment and piping, where the process temperature is between 32°F (0°C) and 300°F (150°C), should be coated to provide protection against corrosion under insulation (CUI).
- When the temperature exceeds 300°F (150°C), no protection is required, as there is no corrosion due to absence of condensed water. Some owners have alternate temperature limits or require all surfaces to be coated regardless of temperature.
- Thermal Spay Aluminum (TSA) is an acceptable material for cyclic services with extreme temperature swings. TSA coatings are preferred by many clients; however, liquid applied coatings such as novolac and epoxy phenolic are also used at temperatures up to 400°F (200°C). When selecting a coating system for stainless steel, assurance that the coating will not promote stress corrosion cracking is a requirement.
- Galvanizing offers several constructability advantages such as minimal damage during handling and being a more forgiving work process.
- For cold insulation, when cellular glass with vapor stops, sealants, and vapor barrier are specified, the insulation system is inherently impervious to water, and will eliminate corrosion concerns. Other sealed insulation systems such as pre-insulated PIR systems with sealed vapor barriers offer the same degree of protection.

3.10. Material Traceability

Manufacturing standards for pipes commonly require a test of chemical composition and a series of mechanical strength tests for each heat of pipe.

- Chemical composition is associated with the heat of pipe. A heat of pipe is all items forged from the same cast ingot, and therefore have the same chemical composition.
- Mechanical tests may be associated to a lot of pipe, which would be all from the same heat and have been through the same heat treatment processes.

3.11. Material Test Reports (MTR)

The manufacturer performs these tests and reports the composition (in a mill traceability report) and the mechanical tests (in a material test report), both of which are referred to by the acronym MTR.

For critical applications, third party verification of these tests may be required; in this case an independent lab will produce a certified material test report (CMTR), and the material will be called certified. By etching the heat number on the components made from this batch of material, it ensures that there is full traceability from the component to the material certificate and therefore the chemical composition of the component is known.

3.12. Quality Assurance (QA)

Maintaining the traceability between the material and the MTR is an important quality assurance issue. QA often requires the heat number to be written on the pipe. Precautions must also be taken to prevent the introduction of counterfeit materials. As a back up to etching/labelling of the material identification on the pipe, Positive Material Identification (PMI) is performed using a handheld device; the device scans the pipe material using an emitted electromagnetic wave (x-ray fluorescence/XRF) and receives a reply that is spectrographically analyzed.

3.13. Material Certificates

Material certificates shall state at least:

- Steel making process
- Mill's name

- Charge or batch number
- Test number
- Material standard or norm.
- Chemical analysis (ladle)
- Mechanical data, certified by the quality control department of the pipe manufacturer, which shall be independent of the production line.
- Temperature of manufacture and type of heat treatment, if required in the material standard, norm or order.
- Results of examination as mentioned in the material standard/norm and in additional requirements (if any).
- Dimensions, including wall thickness.
- Number of different samples tested as mentioned in material standard or norm and in additional requirements (if any).

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CHAPTER – 4

MATERIALS – UNDERGROUND PIPING

4. BURIED PIPING

Two common buried pipe materials are:

1. Cast Iron and Ductile Iron Pipe
2. Plastic Pipes

4.1. Ductile Iron Pipe

Ductile iron pipe (DIP) is an outgrowth of the cast iron pipe industry. While both ductile and cast iron are created by introducing carbon, ductile iron differs in that it is made by adding magnesium, phosphorous and sulfur into the hot molten iron bath. The process gives DIP an ability to slightly deform (bent) without cracking. This is a major advantage of ductile iron pipe. Ductile pipe is used mainly in domestic water distribution service in sizes ranging from 8 inches to 42 inches in diameter.

- **Characteristics**
  - Advantage - Good corrosion resistance when coated. High strength
  - Drawbacks - Heavy
  - Standards - AWWA C151 and the Cement lined DIP: AWWA standard C104.
  - Installation - ANSI/AWWA C600, C105/A21.5

4.2. Plastic Pipes

Plastics are solid materials that contain one or more polymeric substances which can be shaped by flow. Polymers, the basic ingredient of plastics, compose a broad class of materials that include natural and synthetic polymers. Nearly all plastics are made from the latter. In commercial practice, polymers are frequently designated as resins. For example, a polyethylene (PE) pipe compound consists of PE resin combined with colorants, stabilizers, anti-oxidants or other ingredients required to protect and enhance properties during fabrication and service.

Common pipe materials include Polyethylene (PE or HDPE for High- Density PE), polypropylene (PP), Polyvinyl Chloride (PVC), Acrylonitrile-butadiene-styrene (ABS), and Polybutylene (PB).

4.3. Types of Plastic Pipes

Plastics are divided into two basic groups, thermoplastics and thermosets, both of which are used to produce plastic pipe.

4.3.1. Thermoplastics

Thermoplastics soften and melt when sufficiently heated and harden when cooled, a process that is totally reversible and may be repeated. Thermoplastics can be shaped during the molten phase of the resin and therefore can be extruded or molded into a variety of shapes, such as pipe, pipe fittings, flanges or valves.

Common Thermoplastics compositions used in pipe manufacturing include Polyethylene (PE or HDPE for High- Density PE), polypropylene (PP), Polyvinyl Chloride (PVC), Acrylonitrile-butadiene-styrene (ABS), and Polybutylene (PB).

4.3.2. Thermoset Plastics

Thermoset plastics are similar to thermoplastics prior to “curing,” however they become permanently hard when heat is applied and cannot be re-melted after they have been shaped and cured. This is the main difference between thermosets and thermoplastics.

Thermoset plastic pipes are composed of epoxy, polyester and phenolic resins. Fiberglass-reinforced pipe (FRP) is the most common form of thermoset-type pipe. It offers high strength and is corrosion resistant. Fiberglass pipe is suited for the direct bury and aboveground applications in potable water transmission, force main or gravity sewer systems, and all applications where there is a corrosive carrier or external environment.

The drawbacks are high material costs, brittleness (may crack) and high installation cost.

4.4. PVC Pipes

PVC (POLYVINYL CHLORIDE) is, by far, the most common plastic material in domestic potable water piping, sanitary sewers, storm sewers and culverts, chemical processing, chilled water distribution, deionized water, and industrial piping systems. Its basic properties are chemical inertness, corrosion and weather resistance, high strength to weight ratio, electrical and thermal insulators. The service temperature is 140°F. Joining methods are solvent welding, threading (Schedule 80 only), or flanging. It is light in weight and generally grey in color.

- **Limitations**
  - PVC cannot be left out in the sun as the thermal properties will change and damage the pipe.
  - Improper handling can lead to the damage of the pipes by dragging the pipes along the ground or other surfaces.
  - NOT recommended for compressed air, gas and chlorinated hydrocarbon services.
  - These cannot operate beyond 210 psi.

An alternate formulation, called CPVC (CHLORINATED POLYVINYL CHLORIDE) is particularly useful for handling corrosive fluids at temperatures up to 210°F.

Recommended maximum temperature for PVC is 140°F and CPVC is 210°F.

4.5. ABS (Acrylonitrile Butadiene Styrene)

ABS (Acrylonitrile Butadiene Styrene) - Acrylonitrile imparts chemical resistance and rigidity; Butadiene endows the product with impact strength and toughness, while Styrene contributes to ease of processing.

- ABS (Acrylonitrile Butadiene Styrene) is widely used in food and beverage industries and in water and sewerage treatment.
- Its impact strength is high and is comparatively rigid over PVC.
- It is joined by solvent cement.
- It is not resistant to alcohol, petrol, acetic acid and other organic solvents although it is good against diluted inorganic acids, salts, animal fats and oils.
- ABS can operate from -40 to 76°F up to 210 psi. It is important to reduce the allowable pressure suitably when used at higher temperatures.

4.6. Polypropylene (PP) Pipe

Polypropylene is the lightest thermoplastic piping material, yet it has considerable strength, outstanding chemical resistance, and may be used at temperatures up to 180°F in drainage applications. Polypropylene is an excellent material for laboratory and industrial drainage piping where mixtures of acids, bases, and solvents are involved. It has found wide application in the petroleum industry where its resistance to sulphur-bearing compounds is particularly useful in salt water disposal line, chill water loops, and demineralized water. Joining methods are coil fusion and socket heat welding.

- Polypropylene (PP) is lightest of all plastics but strong and durable.
- It offers good resistance to most acids and bases but should not be used with active oxidizing agents like nitric acid and aromatics.
- These are joined by heating or socket welded by inserting a PP wire into it with the help of a hot air gun.
- It can be used up to temperatures of 225°F/107°C, but it becomes brittle at low temperatures. It is not recommended beyond 21psi.

4.7. Polyethylene (PE) Pipe

Polyethylene (PE) and high density polyethylene (HDPE) is the most chemically inert of all commodity plastic materials and is therefore extremely chemical and corrosion resistant. The number one characteristic that sets HDPE apart from other pipe types is that it can be made to be flexible. It can be bent to a radius 25 times the nominal pipe diameter, a feature which can do away with many fittings required for directional changes. With its flexibility, HDPE adopts itself on rough terrain.

This is the most used plastic material and will be discussed more in subsequent paragraphs.

4.8. PTFE (TEFLON) and PFA Pipe

PTFE (Polytetrafluoroethylene also called TEFLON) is virtually inert to most chemicals. This fluoropolymer offers the most unique and useful characteristics of all plastic materials. Products made from this resin handle liquids or gases up to 500°F. The unique properties of this resin prohibit extrusion or injection moulding by conventional methods. When melted, PTFE does not flow like other thermoplastics and it must be shaped initially by techniques similar to powder metallurgy. Normally PTFE is an opaque white material. Once sintered it is machined to the desired part.

PFA (Perfluoroalkoxy) is similar to PTFE. It has excellent melt-processability and properties rivalling or exceeding those of PTFE. PFA permits conventional thermoplastic moulding and extrusion processing at high rates and also has higher mechanical strength at elevated temperatures to 500°F. Premium grade PFA offers superior stress and crack resistance with good flex-life in tubing. It is generally not as permeable as PTFE.

- PTFE cannot be processed by melting or by solvent cements, whereas PFA with same characteristics as TEFLON is melt processable. It is a wonderful lining material.
- PFA has all the excellent chemical resistance qualities of PTFE plus higher mechanical strength at higher temperatures.
- PFA tube is widely used in the services of ultra-pure chemicals like in the semiconductor, laboratory, environmental and pharmaceutical industries. It has a temperature range of -325 to 500°F (-198 to 260°C).

4.9. Plastic Pipe Terminology

- **Low pressure plastic pipelines** – underground thermoplastic pipelines with 4 to 24 inch nominal diameter used in systems subject to pressures of 79 psi or less.
- **High pressure plastic pipelines** – underground thermoplastic pipelines of ½ to 27 inch nominal diameter and subject to pressures from 80 to 315 psi.
- **Class or PSI designation** – refers to a pressure rating in pounds per square inch.
- **Schedule** – refers to a plastic pipe with the same outside diameter and wall thickness as iron or steel pipe of the same nominal size.
- **SDR (Standard Dimension Ratio)** – is the ratio of the outside pipe diameter to the wall thickness.
- **IPS** – refers to plastic pipe that has the same outside diameter as iron pipe of the same nominal size.

4.10. Plastic Pipe Designation

The plastic pipe material designation provides quick identification of the pipe material's principal structural and design properties.

- For example, **PE4710** material designation stands for:
  - The letters PE designate that it is a polyethylene piping material.
  - The first digit, in this example the number 4, identifies the PE resin's density classification in accordance with ASTM D3350, Standard Specification for Polyethylene Plastic Pipe and Fittings

Materials. An increase in density affects certain properties, for example an increase in tensile strength and stiffness. Also, a higher density results in changes to other properties. This ASTM standard classification can range from 2, the lowest value, to 4 the highest value.

- The second digit, in this example the number 7, identifies the material's standard classification for slow crack growth resistance – also, in accordance with ASTM D3350 – relating its capacity for resisting the initiation and propagation of slowly growing cracks when subjected to a sustained localized stress intensification. The standard classification for current commercial grades is either 6 or 7. The 6 denotes very high resistance and the 7 even higher.
- The third and fourth digits combined, the number 10 in this example, denote the material's recommended hydrostatic design stress (HDS) for water at 73°F (23°C), in units of 100psi. In this example the number 10 designates the HDS as 1,000psi.

4.11. Standard Diameters

Standard specifications for PE pipe allow the pipe to be made to either control inside diameters or to control outside diameters. The inside diameter system is typically applied to small diameter sizes only and is intended for use with insert type fittings. The outside diameter systems are intended for use with fittings that require a predictable outside diameter, also independent of wall thickness.

SIDR System

Standard Inside Diameter Sizing (SIDR) convention system is based on the inside diameters of the Schedule 40 series of iron pipe sizes (IPS).

4.12. Dimension Ratio (DR)

Plastic piping standards are widely categorized as Dimension Ratio/Pressure Rated (DR-PR).

The dimension ratio, DR, is the ratio of the pipe outside diameter to the wall thickness. The lower the DR, the thicker shall be the pipe wall - which correlates to a higher pressure rating. It is a given by following expression:

- DR = OD / t

OD = OD - Controlled Pipe Outside Diameter, in.

t = Pipe Minimum Wall Thickness, in.

Plastic pipes which when made to the same Dimension Ratio and from the same kind of material are able to offer the same pressure rating independent of pipe size.

The exception to this practice is the production of thermoplastic pipe in accordance with the industry established SCH 40 and SCH 80 dimensions such as referenced in ASTM D 2447.

4.12.1. Standard Dimension Ratio (SDR)

A Standard Dimension Ratio (SDR) is a specific DR based on ANSI preferred number series. The Series 10 numbers get that name because ten specified steps are required to affect a rise from one power of ten to the next one. Each ascending step represents an increase of about 25% over the previous value. For example, the following are the ANSI specified steps between 10 and 100: 10; 12.5; 16.0; 20.0; 25.0; 31.5; 40.0; 50.0; 63.0; 80.0; 100.

SDR's 9 series include 9, 11, 13.5, 17, 21, 26, and 32.5.

The use of SDR's enables manufacturers to produce pipes to a set of standardized DR's. All SDR's are DR's, but not all DR's are SDR's.

A beneficial feature of the use of preferred numbers is that when a preferred number is multiplied or, is divided by another preferred number, the result is always a preferred number.

The table below lists the Standard Dimension Ratios (all based on preferred numbers) which appear in the various ASTM, AWWA and CSA DR-PR based standards for PE pipes.

Based on Mean Diameter (Dm/t) (Same numerical value as ANSI Preferred Number, Series 10)	Based on Outside Diameter SDR = (Do/t (Series 10 Number + 1)	Based on Inside Diameter SIDR = (Di/t) (Series 10 Number – 1)
5.0	6.0	4.0
6.3	7.3	5.3
8.0	9.0	7.0
10.0	11.0	9.0
12.5	13.5	11.5
16.0	17.0	15.0
20.0	21.0	19.0
25.0	26.0	24.0
31.5	32.5	30.5
40.0	41.0	39.0

50.0	51.0	49.0
63.0	64.0	62.0

And, the standard pressure ratings for water, at 73°F (23°C), which are commonly recognized by DR-PR standard specifications for PE pipe, are as follows: 250; 200; 160; 125; 100; 80; 63; 50; and 40 psig. However, individual standards generally only cover a selected portion of this broad range.

The result of the use of these standard preferred number values is that a pipe's standard pressure rating (PR) is a consistent result, independent of pipe size, which simply depends on its standard dimension ratio and the standard HDS of the material from which the pipe was made. This relationship is shown below:

Standard Pressure Ratings for Water, at 73°F (23°C), for SDR-PR Pipes, psig

Standard Dimension Ratio		Standard Pressure Rating (psig) as a function of a Material's HDS for Water, at 73°F (23°C), psi		
SDR (In the Case of Pipes Made to Standard OD's)	SIDR (In the Case of Pipes Made to Standard ID's)	HDS = 630psi (4.34 MPa)	HDS = 800psi (5.52 MPa)	HDS = 1000psi (6.90 MPa)
32.5	30.5	40	50	63
26.0	24.0	50	63	80
21.0	19.0	63	80	100
17.0	15.0	80	100	125
13.5	11.5	100	125	160
11.0	9.0	125	160	200
9.0	7.0	160	200	250

Important:

– Pipes with a lower SDR can withstand higher pressures.

4.13. Pressure Rating

For the purposes of pressure pipe design, the pipe's pressure rating (PR) is determined by the hydrostatic design stress (HDS) that is assigned to the material from which the pipe is made.

- For example, HDPE (PE4710) DR 17 pipe has a static pressure rating for water of 125 psig.
- OD controlled pressure pipes are pressure rated per ASTM F714 using the formula below.

$$PR = \frac{2\,HDS\,f_T\,A_f}{(DR-1)}$$

Where:

- PR = Pressure Rating, psi
- HDS = Hydrostatic Design Stress at 73°F, psi (refer vendor info)
- A_f = Environmental Application Factor, A_f = 1 for Water: Aqueous solutions of salts, acids and bases, Sewage, Wastewater, Alcohols, Glycols (anti-freeze solutions) etc. and A_f = 0.5 for Fluids such as solvating/permeating chemicals in pipe or soil (typically hydrocarbons) in >2% concentrations, crude oil, fuel oil etc.
- f_T = Service Temperature Design Factor, f_T = 1 for ≤ 80°F (27°C), f_T = 0.8 for ≤ 100°F (38°C); f_T = 0.63 for ≤ 120°F (49°C) and f_T = 0.5 for ≤ 140°F (60°C)
- DR = OD Controlled Pipe Dimension Ratio

- Working Pressure Rating
  - The working pressure rating (WPR) is based on the actual system requirements and is a pressure rating for pipe with flowing water. The WPR includes an allowance for water hammer surge pressures.
  - At a daily recurring average flow surge velocity of 5 fps and at 80°F, the working pressure rating of HDPE (PE4710) DR 17 pipe is also125 psig; similarly, the working pressure rating for PVC DR 18 is 120 psig (reference - AWWA C900-07, Equation 4). As such, PE 4710 has a higher working pressure rating than PVC at these common conditions.

The table below provides Pressure Rating and Allowable Total Pressure during Surge for PE4710 pipe at 80°F.

Pipe Dimension Ratio (DR)	Pressure Class	Pressure Rating	Allowable Total Pressure During Recurring Surge	Allowable Total Pressure During Occasional Surge
DR 9	250 psi	250 psi	375 psi	500 psi
DR 11	200 psi	200 psi	300 psi	400 psi

DR 17	125 psi	125 psi	185 psi	250 psi

(Source Reference - AWWA C901-08)

4.14. Plastic Pipe De-rating

The pressure rating of a plastic pipe is determined at 73.4°F. The strength of a plastic pipe decreases as the fluid temperature becomes warmer and therefore the plastic pipe needs to be de-rated for higher temperatures. The table below shows a de-rating factor for the increase in fluid temperature.

Temperature (°F)	Multiply Pressure Rating by:
73.4	1.00
80	.93
90	.77
100	.67
110	.51
120	.43
130	.33
140	.23

For example, the maximum working pressure for PVC piping is above 150 psig for all pipe sizes through 8 inches in diameter, but this is only for temperatures of 73.4°F. Any temperature above 73.4°F will result in a reduced working pressure within the piping system up to a maximum of 140°F. At this temperature the de-rating factor is 0.23, where it is 1.0 at 73°F.

4.15. Plastic Pipe Standards

Pipe manufacturers follow requirements set by the American Society of Testing Materials (ASTM) or American Water Works Association (AWWA) for specific pipe materials. Specification standards cover the manufacture of pipes and specify parameters such as internal diameters, loadings (classes), and wall thicknesses (schedules). The methods of pipe construction vary greatly with the pipe materials.

Poly vinyl chloride (PVC) Pipe	
Plastic pipe - Schedule 40, 80, or 120	ASTM D1785 or D2466
Pressure rated pipe - SDR Series	AWWA C900 or ASTM D2241
Plastic drain, waste, and vent pipe and fittings	ASTM D2665
Composite sewer pipe	ASTM D2680

Type PSM PVC sewer pipe and fittings	ASTM F3034
Large-diameter gravity sewer pipe and fittings	ASTM F679
Smooth-wall Underdrain Systems for Highway, Airport, and Similar Drainage	ASTM F758
Type PS-46 gravity flow sewer pipe and fittings	ASTM F789
Profile gravity sewer pipe and fittings based on controlled inside diameter	ASTM F794
Corrugated sewer pipe with a smooth interior and fittings	ASTM F949
Pressure pipe, 4-inch through 12-inch for water distribution	AWWA C900
Water transmission pipe, nominal diameters 14-inch through 36-inch	AWWA C905
Polyethylene (PE) pipe	
Schedule 40	ASTM D2104
SIDR-PR based on controlled inside diameter	ASTM D2239
Schedules 40 and 80 based on outside diameter	ASTM D2447
SDR-PR based on controlled outside diameter	ASTM D3035
High density polyethylene (HDPE) pipe	
Plastic pipe and fittings	ASTM D3350
SDR-PR based on controlled outside diameter	ASTM F714
Plastic moldings and extrusion compounds	ASTM D1248
Heat joining polyolefin pipe and fittings	ASTM D2657
Acrylonitrile-Butadine-Styrene (ABS) pipe	
Plastic pipe, schedules 40 and 80	ASTM D1527
Plastic pipe, SDR-PR	ASTM D2282
Schedule 40 plastic drain, waste, and vent pipe	ASTM D2661
Composite sewer pipe	ASTM D2680
Sewer pipe and fittings	ASTM 2751

4.16. HDPE v/s PVC

Description	PE	PVC
Type	HDPE is Semi-Crystalline Thermoplastic.	PVC is Amorphous Thermoplastic
Life Expectancy Resistance to Corrosion Underground	Generally good life expectancy. However, has low stress resistance and poor rigidity.	Long life expectancy if properly laid and backfilled.
***Safe Working Pressures (PSI)**	Rating from 80-160 PSI. (Surge pressures in HDPE	Ratings from 80-600 PSI.

	pipe are significantly lower than PVC pipe due to the lower value of dynamic modulus. For example, a velocity change of 5 fps would cause a 51 psig surge in 7 HDPE DR 17 pipe and 87 psig surge in PVC DR 18 pipe. Lower surge pressures often means longer life for pumps and valves in an HDPE pipeline, as well as lower pressure class pipes).	
Resistance to Puncturing and Rodents	Low resistance.	Much stronger and stiffer.
Effect of Sun and Weather	Weakens with exposure.	Weakens with exposure.
Ease of Joining, Laying and Bending	Easy to join using the heat fusion procedure. Fused joints are self –restrained and do not require thrust blocks. Can be installed with horizontal directional drilling (HDD) techniques, which is a trenchless installation technique.	PVC pipes use gasketed – push-on joints. Rigid, but will bend on long radius. Can be bent by heating. PVC pipes require Bolt on, or Thrust Blocks.
Leakage	The joints are tighter and the leakage rate is zero.	PVC installations have leakage rates as high as 10 percent.
Cost	Low cost.	Costlier than HDPE pipes.

PE pipe can withstand impact much better than PVC pipe, especially in cold weather installations where other pipes are more prone to cracks and breaks. Because heat fused PE joints are as strong as the pipe itself, it can be joined into long runs conveniently above ground and later, installed directly into a trench or pulled in via directional drilling or by using the re-liner process.

Many of the PE resins used in PE pipes are stress rated not only at the standard temperature, 73°F, but also at an elevated temperature, such as 140°F. Typically, PE materials retain greater strength at elevated temperatures compared to other thermoplastic materials such as PVC. At 140°F, PE materials retain about 50% of their 73°F strength, compared to a PVC pipe which loses nearly 80% of its 73°F strength when placed in service at 140°F. As a result, PE pipe materials can be used for a variety of piping applications across a very broad temperature range.

4.17. Standard Sizes

Most plastic piping products are manufactured from 1/4” (6 mm) diameter through 120” (3050 mm) diameter under applicable industry standards (ASTM, AWWA, etc.) for pressure and non-pressure applications. HDPE pipe is available both in iron pipe (IPS) and ductile iron pipe sizes (DIPS). IPS sized HDPE pipe has the same outside diameter as black iron or carbon steel pipe.

4.18. Standard Lengths

Standard straight lengths for extruded pipe are 40 feet long; however, shorter lengths or lengths 60 feet long or longer, depending on transportation restrictions, may be produced.

4.19. Lined Piping

Metallic pipe is strong and easy on cost and work. CS is most common material, but its corrosion resistance is very poor. Stainless steel scores better in corrosion resistance but is expensive.

Lined pipes combine the mechanical strength of steel and the corrosion resistance of plastics. They have wide operating range from -18 to 500°F (-28 to 260°C), offer low pressure drop and available in sizes ½” through 12” and beyond. Liners can be bonded and locked or loose lined. Bonded plastic line pipe can operate at full vacuum. Pipes are generally flanged in lengths of 20 ft. (6 meters) with the lined material protruding onto the flange faces. A wide range of linings are available to choose from:

- Polypropylene (PP)
- PTFE
- Rubber can be natural or synthetic such as Neoprene, Hypalon, Butyl, Chlorobutyl, Nitrile, EPDM etc.
- Glass lined pipes are used for extreme corrosion protection.
- Cement mortar lined pipes were used traditionally for water and sewerage transport. HDPE has taken over in water transport so cement mortar lines are hardly used.

PVC and CPVC are rarely used as lining material because of low temperature range. However they are widely used as a straight pipe in most domestic water applications.

4.20. Cost Comparisons

Costs for piping comparisons should include both the costs of the materials as well as the construction costs. The pipe cost is usually given in dollars per unit length, traditionally in dollars/linear foot, plus the costs of the fittings, connections and joints. Construction costs will depend on the type of digging necessary, special field equipment requirements, and an allowance for in-field adjustments to the system. Access to pipe systems will also be a relevant cost factor, as manhole spacing is dependent on pipe size.

The table below provides a sample typical average cost for sanitary sewers (excluding service connections and manholes). The cost per linear foot in the table is based on an average trench depth of eight feet and excludes service connections and manholes.

Average Cost/Linear foot by pipe diameter (2005 data)

Pipe Material	2"	4"	6"	8"	12"	15"	18"	24"
Concrete	-	-	$25	$30	$38	$50	$65	$110
Ductile Iron	-	-	-	$38	$50	N/A	$75	$110
PVC	$15	$19	$23	$25	$30	$38	$50	$75
PE	-	$7	$12	$14	$9*	-	$16*	-
FRP	$21	$30	$42	$60	-	-	-	-

Summarizing:

Plastic pipes are widely used today. Some characteristics are underlined below:

- Plastic pipes can be used in a wide temperature range of -76 to 140°F and have an estimated service life of conservatively 50 to 100 years.
- The coefficient of thermal expansion for unrestrained polyethylene is very high, about 10 times that of steel. An approximate "rule of thumb" is 1/10/100, that is, 1 in for each 10°F change for each 100 ft of pipe. This is a significant length change compared to other piping materials and should be taken into account when designing unrestrained piping such as surface and above grade piping. A temperature rise results in a length increase while a temperature drop results in a length decrease.

- HDPE material exhibits a lot of advantages over traditional materials for pressure pipe applications. These pipes can be easily welded by butt fusion or electro-fusion coupler which creates a leak free joint stronger than the pipe itself.
- HDPE is preferred over steel or PVC tubes as it tends to rip or tear in a malfunction instead of shattering and becoming shrapnel like the other materials.
- HDPE can carry potable water, wastewater, slurries, chemicals, hazardous wastes and compressed gases. It is currently the most recommended material for municipal water transport, as it will not support biological growth.
- HDPE is NOT recommended for sanitary sewer gravity installations because the flexible properties of the pipe can cause dips in the gravity runs.

This completes the 2nd module of the 9 module series. Please refer to the other course modules in Annexure -1.

Annexure -1

DESCRIPTIONS OF ALL PIPING COURSES

MODULES 1 to 9

MODULE 1:	**PROCESS PIPING FUNDAMENTALS, CODES AND STANDARDS**
CHAPTER -1:	THE BASICS OF PIPING SYSTEM This chapter covers the introduction to the pipe sizes, pipe schedules, dimensional tolerances, pressure ratings, frequently used materials, criterial for material selection, associations involved in generating piping codes, design factors depending on fluid type, pressure, temperature and corrosion, roles and responsibilities of piping discipline, key piping deliverables and cost of piping system.
CHAPTER – 2:	DEFINITIONS, TERMINOLOGY AND ESSENTIAL VOCABULARY This chapter provides essential definitions and terminology, each piping engineer and designer should familiar with. This is based on the Author's experience on the use of vocabulary in most design engineering, procurement and construction (EPC) companies.
CHAPTER – 3:	DESIGN CODES AND STANDARDS This chapter discusses the associations involved in generating piping codes and material specifications. It provides description of various ASME pressure piping codes such as B31.1 Power Piping, B31.3 Process Piping, B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons, B31.5 Refrigeration Piping and Heat Transfer Components, B31.8 Gas Transmission and Distribution Piping Systems, B31.9 Building Services Piping and B31.11 Slurry Transportation Piping Systems. It also provides information on the associations involved in material specifications such as API - American Petroleum Institute Standards, ASTM – American Society of Testing Materials, ASME Piping Components Standards, American Welding Society (AWS), American Water Works Association (AWWA) and EN – European Standards.

MODULE 2:	**PROCESS PIPING MATERIALS**
CHAPTER -1:	PIPING MATERIAL SELECTION & CHARACTERISTICS This chapter discusses about the selection criteria for piping materials covering service life, temperature, and pressure and corrosion considerations. It discusses the characteristics of piping materials required to prevent failures resulting from the environment, normal operation time exposure and upset conditions.
CHAPTER – 2:	MATERIALS – METALLIC PIPING This chapter discusses the most commonly used ASTM material

	designation standards for Carbon Steel, Stainless Steel, Alloy Steels, Duplex Steel, Cast Iron, Copper, Aluminum; Titanium and other materials. It gives the pertinent information of all relevant ASME/ASTM codes and standards highlighting the applications these are suited for.
CHAPTER -3:	SPECIAL PIPING MATERIALS This chapter discusses some specific considerations to piping selection for extreme high and cold temperatures. It provides specific information for hydrocarbon industry and the piping selection issues for mitigating the effects of Wet CO2 corrosion, Hydrogen exposure, Offshore environment, Sulfides and Sulfurous Gases, Halogenation Environments, Carburizing, Nitriding, Sulfur, Amine, Caustic and Chloride environment. Other applications include the cooling water, fire water, sour water services and Microbiological Induced Corrosion (MIC).
CHAPTER – 4:	MATERIALS – UNDERGROUND PIPING This chapter discusses the piping materials for underground services, including ductile iron, concrete pipes, plastic materials such as polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), fiber reinforced plastic (FRP), reinforced polymer mortar (RPMP), polypropylene (PP), High density polyethylene (HDPE), cross-linked high-density polyethylene (PEX), polybutylene (PB), and acrylonitrile butadiene styrene (ABS).

MODULE 3:	**PROCESS PIPING HYDRAULICS, SIZING AND PRESSURE RATING**
CHAPTER -1:	PIPELINE HYDRAULICS This chapter covers basic hydraulics definitions, terminology and flow characteristics in pipe. It discusses the various flow conditions, continuity equation, Bernoulli's equation, flow regimes, laminar flow & turbulent flow, Reynold's Number (Re) and Moody's Chart for hydraulic line sizing. Procedures are included for calculating pressure drop considerations using the Darcy–Weisbach Equation and Hazen–Williams Equation. Finally, it covers the economic pipe sizing based on least annual cost approach.
CHAPTER – 2:	DESIGN OF PRESSURE PIPING This chapter deals with the methods to compute the pipe wall thickness. It describes the design conditions, pressure-temperature relationships, allowable stresses, theories of failure and the importance of hoop stress and longitudinal stress in pressure pipe sizing. It gives the pertinent information of all relevant ASME/ASTM codes and thickness allowances with examples. It includes an annexure at the end, which provides some solved examples.

MODULE 4:	PROCESS PIPING JOINTS, FITTINGS AND COMPONENTS
CHAPTER -1:	JOINTS AND FITTINGS This chapter describes the various types of pipe joints (weld, socket, thread, flanged), fittings (bends, elbow, tees, reducers, Stub ends, couplings, cross, cap, plug and nipples), Special pipe olets (weldolets, sockolets, threadolets, elbowlets, latrolets), expansion joints, strainers and traps. It discusses the criteria for the selection, and provides reference to the relevant ASME codes. Standard symbols and abbreviations are also shown.
CHAPTER – 2:	FLANGES, GASKETS & BOLTS This chapter covers the flanges, gaskets and bolts. It discusses the pressure rating concept for flanges, the types of flanges including weld neck, slip-on type, socket weld, reducing flange, lap joint, blind flange and orifice flanges. The selection recommendation for flat face, raised face and ring type flange is discussed. Selection criteria for different types of gaskets, bolts and fasteners, their standards, the advantages and limitations of each are provided. Reference of relevant ASME codes and their proper service applications in pressure piping applications is provided.
CHAPTER – 3:	VALVES This chapter describes the various types of valves and their applications. The characteristics, ratings, advantages and disadvantages of most commonly used valves such as gate valve, ball valve, globe valve, butterfly valve, check valve, diaphragm valve and various safety relief valves are provided. The material of construction and selection criteria is covered. Reference of relevant ASME codes and their proper service applications in pressure piping applications is provided.

MODULE 5:	PROCESS PIPING MATERIALS MANAGEMENT
CHAPTER -1:	PIPING MATERIAL MANAGEMENT The chapter describes the various inputs to the piping material activities such as the type of fluid service as per ASME B31.3, Process Flow Diagrams (PFD's), Piping and Instrumentation Diagrams (P&ID's), the line lists, the equipment data sheets and the nozzle schedules.
CHAPTER – 2:	PIPING DESIGN CRITERIA This chapter covers some good engineering practices to aid piping engineers and designers to carry out the design activities. It discusses the engineering guidelines for pipes, fittings, valves, insulation, corrosion, supports and anchors, expansion and contraction, vents and drains, utility stations, pipe line welding, non-destructive examination and heat tracing. Reference is made to appropriate codes and standards.

CHAPTER– 3:	PIPING MATERIAL SPECIFICATION (PMS) This chapter describes how PMS is generated, typical format of material specification; line numbering system, pipe class designation, fluid service designation, insulation service and piping material index.
CHAPTER– 4:	PIPE FABRICATION AND INSTALLATION This chapter describes the difference between the field fabrication, shop fabrication for generating spools and modular skid fabrication. It discusses the pros and cons of installation approaches and the technical requirements for shop fabrication.
CHAPTER– 5:	MATERIAL REQUISITION AND CONTROL This chapter describe the different stages of material take-offs, roles and responsibilities of procurement vs engineering, preparation of material requisition, technical requirements for materials, inspection and testing requirements, quality assurance plan, material traceability requirements, certification, storage and handling requirements, different attachments to material requisition and testing requirements.
CHAPTER– 6:	BID TABULATION This chapter describes the process of technical evaluation, commercial evaluation, qualifying criteria for bidders, purchase order and vendor document review and approval process.

MODULE 6:	**PROCESS PIPING PLANT DESIGN AND LAYOUT**
CHAPTER -1:	PLANT DESIGN AND LAYOUT This chapter describes the need for the Plot Plan, key issues and challenges. It discusses the key features in the development of a plot plan: Terrain, Throughput, Safety and Environment. It provides guidance on how to demarcate site area for process equipment, utilities and service buildings.
CHAPTER – 2:	EQUIPMENT LAYOUT This chapter covers the equipment layout principles to carry out the design activities. It provides the engineering guidelines for locating process equipment, utilities, loading and unloading facilities, piperacks and sleepers. It discusses the clearance and accessibility for crane, forklift, tube bundle pulling, and the different equipment such as process vessels, pumps, heat exchangers, furnaces (Fired Heaters), compressors, tank farms and LPG storage tanks. Reference is made to appropriate codes and standards.
CHAPTER– 3:	OSHA GUIDELINES FOR STAIRS, LADDERS AND PLATFORMS This chapter discusses the OSHA guidelines for Stairways, Handrails, Ladders (portable and fixed type), Cages and Wells, Safety Devices, and

	the layout and access requirements for Platforms (Ladders and Stairs).
CHAPTER– 4:	PIPING LAYOUT This chapter describes the basic principles of piping layout covering, safety, grouping, interferences, supports, pipe ways and rack piping. It discusses the offsite and yard piping, underground piping, utility stations, hose stations etc. The chapter provides system specific information for fire protection, compressed air, steam distribution, fuel oil systems. It also provides equipment specific guidelines for Control valves, Relief valves, Strainers, Instrumentation, Column/Tower and Vessel Piping, Heat Exchanger Piping, Cooling Towers, Heater/Furnace Piping, Pump Piping, Compressor Piping, Turbines and Flare Piping.
CHAPTER– 5:	PIPING DRAWINGS This chapter describes the various type of piping drawings, Orthographic Plans, Piping Isometric Drawings and Spool Isometrics. It provides information on the piping arrangement in 3-D Models, CAD layout in 2-D and 3-D environment, stages of model review, database capabilities and 3-D software tools.

MODULE 7:	**PROCESS PIPING SUPPORTS AND COMPONENTS**
CHAPTER -1:	OVERVIEW OF PIPE SUPPORTS This chapter provides an overview of pipe supports. It introduces readers to the function of supports; primary supports and secondary supports including hangers, restraints and braces. It discusses the necessary input and design steps for the selection of supports.
CHAPTER – 2:	PRIMARY SUPPORTS This chapter discusses yard piping and differentiates between piperacks and sleepers. It discusses the various configurations of piperacks and their layout requirements.
CHAPTER– 3:	SECONDARY SUPPORTS This chapter discusses the type of supports including rigid hangers, variable spring hangers, constant hangers, pipe shoes, various types of clamps, saddles, trunnion supports, roller supports, different types of brackets, restraints, snubbers, struts, braces, PTFE slide bearings etc.

MODULE 8:	**PROCESS PIPING STRESS ANALYSIS**
CHAPTER– 1:	FAILURE ANALYSIS This chapter discusses the material characteristics, strength, stress-strain curve, yield point, modulus of elasticity and relationship of elastic properties. It discusses various types of pipe failures and common causes

	of failures. It also provides information on the specifications of steel pipes, pipe grades, and ASTM material designation.
CHAPTER -2:	THERMAL EXPANSION AND FLEXIBILITY This chapter discusses the pipe failures due to stress caused by temperature variations and material expansion and contraction. It provides methods of increasing flexibility in the design by use of expansion loops, expansion joints, anchors and guides, and directional changes.
CHAPTER -3:	PIPE STRESS ANALYSIS This chapter discusses the fundamental concepts and factors responsible for pipe stress. It discusses theories of failure, hoop and longitudinal stresses, and acceptability conditions for allowable stress as prescribed by ASME B31.1 and B31.3 codes. It provides information on analyzing equipment nozzle loads, various prerequisites, tools and checklists for stress analysis.
CHAPTER -4:	PIPE SUPPORTS SPACING This chapter discusses the allowable pipe spans based on stress and deflection criteria. It includes examples to calculate the support spans and provides recommended spacing table and thumb rules.

MODULE 9:	**PROCESS PIPING CORROSION, INSULATION AND TESTING**
CHAPTER– 1:	PIPE CORROSION AND COATINGS This chapter discusses corrosion basics and the types of corrosion including Galvanic Corrosion, Pitting Corrosion, Selective Leaching, SS Corrosion, Crevice Corrosion, Microbial Corrosion, Cavitation and Erosive Corrosion, Chemical Corrosion, High-temperature Corrosion, Stray Current Corrosion, Stress Corrosion Cracking, etc. It discusses the different methods of protection from corrosion, material selection, use of inhibitors, cathodic protection, galvanizing, surface treatments, etc.
CHAPTER -2:	PIPE INSULATION This chapter discusses the different types of insulation materials and their applications. It provides the characteristics of common insulating materials such as Mineral Fiber, Cellular Materials, Calcium Silicate, Expanded Silica (Perlite), Elastomeric Foam, Foamed Plastic, Expanded Polystyrene and Polyurethane (PUR). It provides information on the protective coverings and finishes.
CHAPTER -3:	PRESSURE AND LEAK TESTING This chapter discusses the Hydrostatic and Pneumatic Testing methods, their requirements, challenges, and pros and cons. It describes when to perform the pressure testing and the applicable test pressures.

CHAPTER -4:	INSPECTION AND TESTING This chapter discusses various destructive and non-destructive testing methods such as Ultrasonic Testing, Eddy-Current Testing, Magnetic Particle Testing, Radiographic (X-Ray) Testing, and Dye-penetrant Testing, etc. It discusses the importance of material traceability.
CHAPTER -5:	PIPE AND COMPONENT IDENTIFICATION This chapter discusses the need for marking and color coding for pipe identification, pipe labelling in plant, component identification, packing and preservation, etc.

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