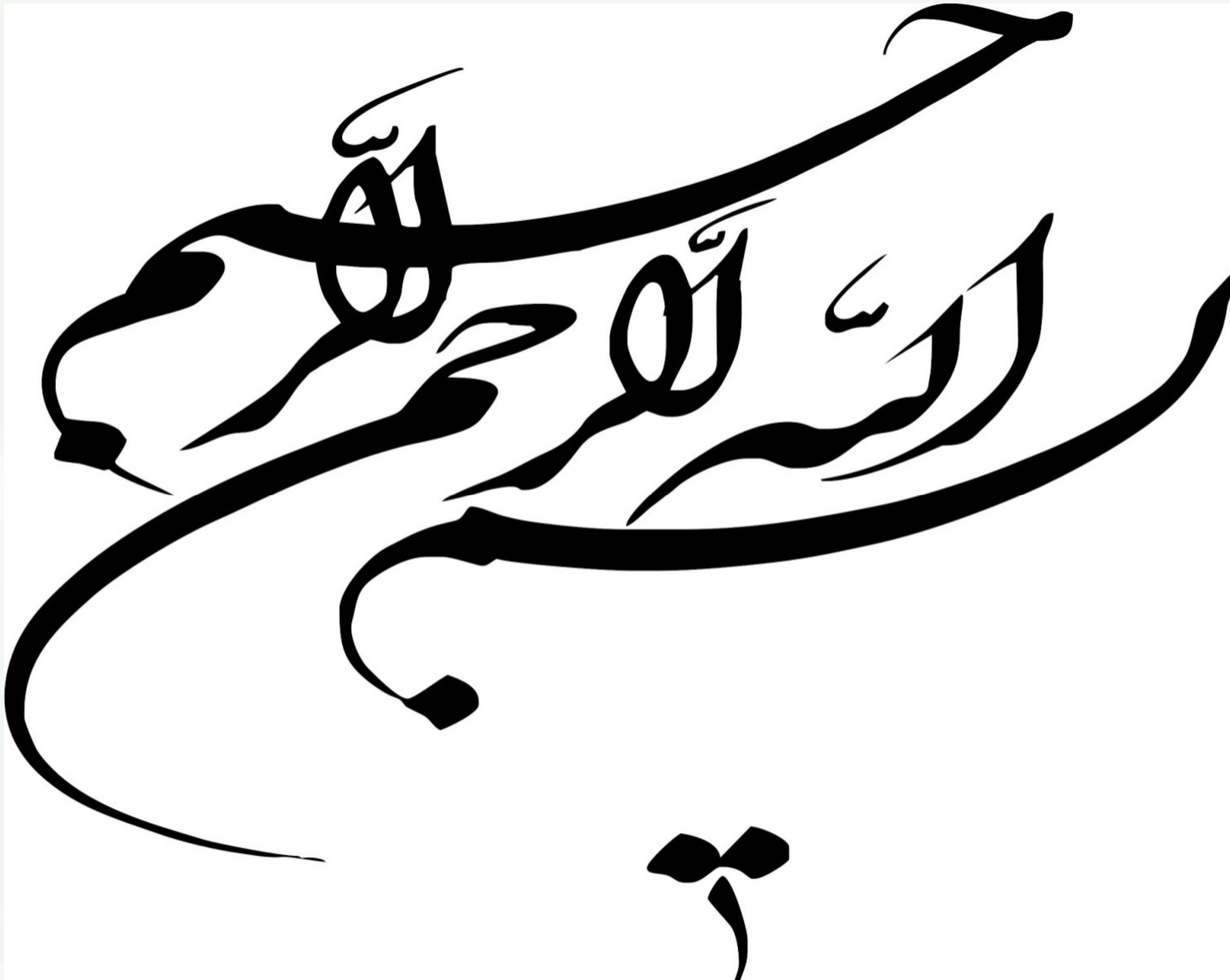
بسم الله الرحمن الرحیم

K. N. Toosi University of Technology
Faculty of Materials Science and Engineering

Selection of Engineering Materials

Sixth Session
(Material Selection Process- 4)

Reza Eslami-Farsani

Material Selection Based on Corrosion Resistance

- **The main factors affecting the corrosion behavior of materials can be classified as follows:**

1- Environmental variables

2- Design variables

3- Material composition variables

In other words, the behavior of materials in corrosive environments changes with slight variations in the environment, material composition, and design of the component.

Material Selection Based on Corrosion Resistance

- **The variables affecting the corrosion behavior of materials include:**

1- Environmental conditions (humidity, pollution, etc.)

2- Physical state of the environment, i.e., solid, liquid, gas, or a combination of them

3- Ionization, aeration, and oxygen content of the corrosive environment

4- Bacterial content of the environment

Material Selection Based on Corrosion Resistance

- ✓ In metallic materials, the most important controlling factor for atmospheric corrosion is the amount of humidity present in the air and ultimately the formation of an aqueous solution on the metal surface.
- ✓ Warm and dry or cold and icy conditions create less corrosion in a humid environment.
- ✓ The risk of corrosion in clean environments is also lower compared to industrial environments (containing sulfur dioxide) and marine environments (containing salt).
- ✓ The exposure of metal to light, wind, or contaminant sources is another significant factor in the atmospheric corrosion rate.

Material Selection Based on Corrosion Resistance

- ✓ In structures buried under the soil, increased soil porosity and the presence of water lead to a faster corrosion rate.
- ✓ Porosity, in addition to allowing continuous access of oxygen to the surface, causes increased activity of aerobic microorganisms, which leads to localized changes in aeration, consumption of protective organic coatings, and the production of corrosive hydrogen sulfide.
- ✓ Generally, the corrosion of chalky or dry sandy soils is minimal due to high electrical resistance, but clayey and salty soils have the highest corrosion rates.

Material Selection Based on Corrosion Resistance

- ✓ The amount of oxygen, dissolved salts, and suspended solids in water control the corrosion rate of submerged structures.
- ✓ Since the dissolution of air is the factor for oxygen entry into the water, the amount of oxygen changes with variations in depth and flow rate of water.
- ✓ Soft and fresh water is more corrosive than hard water because carbonate deposits protect the surface of the piece.
- ✓ The presence of chloride ions in seawater increases electrical conductivity and corrosion rate.

Material Selection Based on Corrosion Resistance

- The presence of organic materials such as bacteria and algae in water reduces corrosion rate in the protected area, but due to localized deaeration, it will accelerate the attack.
- Increasing water temperature leads to a higher corrosion rate. In chemical facilities, factors such as temperature, concentration of chemicals, fluid velocity, aeration level, metal purity, and applied stress determine the corrosion rate.
- Generally, if the oxide layer or surface protector becomes locally unstable or damaged, the corrosion rate will significantly increase.

Material Selection Based on Corrosion Resistance

- **Design variables affecting the corrosion rate include:**

✓ Applied stress on the material in use

✓ - Operating temperature of the component

✓ - Relative velocity of the corrosive environment compared to the material

✓ - Surface contact between the desired material and other materials

✓ - Possibility of stray current

✓ - Geometry and physical shape of the component

Material Selection Based on Corrosion Resistance

- **The most important factors affecting corrosion resistance of a material include:**

✓ - Chemical composition and presence of inclusion

✓ - Nature and distribution of microstructural elements

✓ - Surface quality and coatings

✓ - Manufacturing process

Generally, pure materials have higher corrosion resistance.

Material Selection Based on Corrosion Resistance

- **Carbon Steels and Cast Irons**

✓ The corrosion resistance of carbon steels and cast irons with suitable mechanical properties and low cost, except against concentrated sulfuric acid and alkalis, is average.

✓ Chromium is a factor in increasing atmospheric corrosion resistance in steels, and nickel also enhances resistance to NaOH.

✓ The presence of 3% chromium improves resistance to the formation of oxide and sulfide scales. Soft steels are resistant to scaling up to approximately 500 °C.

Material Selection Based on Corrosion Resistance

- **Stainless Steels**

✓ Stainless steels are a group of highly corrosion resistant steels with wide engineering applications.

✓ These steels have lower corrosion resistance in chloride-containing environments under stress compared to structural steels.

✓ Improper manufacturing processes and heat treatments can exacerbate intergranular corrosion, cracking in corrosive and stressed environments, as well as pitting and crevice corrosion in these steels.

Material Selection Based on Corrosion Resistance

- **Stainless Steels**

✓ The corrosion resistance of stainless steels increases with the increase of chromium content, because the corrosion resistance factor is the presence of a thin layer of chromium hydroxide on their surface, which is considered an inactive layer.

✓ Nickel is a stabilizing element of austenite, and its presence in high-chromium steels improves resistance in some oxygen-free environments.

Material Selection Based on Corrosion Resistance

- **Stainless Steels**

✓ Manganese contributes to the stability of austenite and can replace a part of nickel, but it does not cause much change in the corrosion resistance of high chromium steels.

✓ Molybdenum increases the strength of the passive layer and increases the resistance to creating pits in the vicinity of sea water.

✓ Elements such as copper, aluminum and silicon also have a positive effect on the corrosion resistance of stainless steels.

Material Selection Based on Corrosion Resistance

- **Nickel**

✓ Nickel has relatively high corrosion resistance and is particularly used for storing caustic alkalis. This material is resistant to cracking in chloride-containing environments and under stress, but in caustic environments with soluble inclusion under high stress, it is susceptible to cracking.

✓ Inconel (Ni/Cr/Fe-78/16/6) is resistant to many acids and has very high resistance to nitriding at high temperatures.

Material Selection Based on Corrosion Resistance

- **Nickel**

✓ Nimonic alloys (Ni/Cr-80/20) have special strength and suitable wear resistance at high temperatures.

✓ Monel alloys (Ni/Cu-70/30) have corrosion properties similar to Ni and are cheaper. They are used to store seawater and brackish water flowing at high speed. They are also useful for storing sulfuric acid and other non-oxidizing acids, but their resistance to oxidizing acids (such as nitric acid), iron chloride, sulfur dioxide, and ammonia is very low.

Material Selection Based on Corrosion Resistance

- **Copper**

✓ Copper is a noble metal and highly resistant to corrosion.

✓ Copper is compatible with marine, urban, and industrial environments, and easily tolerating seawater and regular water.

✓ Aluminum bronzes have good resistance in potassium chloride solutions, non-oxidizing mineral acids, and many organic acids.

✓ Tin bronzes are resistant to many environments, including water and soil.

✓ The addition of phosphorus improves the resistance to oxidation of copper alloys.

Material Selection Based on Corrosion Resistance

- **Tin**

✓ More than half of the produced tin is used for protective coatings of steel and other metals.

✓ Tin is used as a coating of steel cans for storing food and drink products. In sealed cans containing food products, tin is a sacrificial component and protects the iron body. Tin is resistant to relatively pure water and dilute mineral acids in the absence of oxygen.

✓ In addition to corrosion resistance, tin is a non-toxic element and is a suitable coating against organic materials.

Material Selection Based on Corrosion Resistance

- **Lead**

✓ Lead is mainly used for corrosion resistant applications, especially against sulfuric acid.

✓ In the vicinity of the corrosive environment, a sulfate, alkaline and phosphate layer is formed on the lead surface, which protects it.

✓ Lead is used to store neutral solutions, sea water, soil, and its alloy with 6% copper is used to store sulfuric acid, chromic acid, hydrofluoric acid, and phosphorus.

✓ Nitric acid, hydrochloric acid, and organic acids cause lead corrosion.

Material Selection Based on Corrosion Resistance

- **Aluminum**

✓ Although aluminum is an active metal, but the aluminum oxide layer formed on the surface provides corrosion protection in most environments. This layer is quite stable against most acidic and neutral solutions, but very weak against alkalis.

✓ The said oxide layer easily tolerates various organic compounds, including fatty acids, and is formed quickly in most environments, and it can be artificially created by anodizing.

Material Selection Based on Corrosion Resistance

- **Aluminum**

✓ The non heat treatable aluminum alloys pure aluminum have a high resistance to general corrosion, but due to the dependence of their resistance on the surface oxide layer, they are prone to local corrosion in grooves and undercoatings.

✓ In heat treatable alloys (2XXX and 7XXX series), due to the presence of copper, strength is the first priority and corrosion is second, because they have less resistance to general corrosion.

Material Selection Based on Corrosion Resistance

- **Titanium**

✓ Titanium has a very stable, adhesive, and protective oxide layer on its surface, providing excellent resistance to corrosion and immunity to various types of corrosion in seawater and chlorinated solutions.

✓ Titanium is also resistant to strong oxidizing hot solutions.

✓ Titanium exhibits suitable resistance to abrasive corrosion in seawater. It is resistant to moist chlorine gas, but if the humidity drops below 0.5%, corrosion rapidly occurs. Hydrofluoric acid is one of the substances that can destroy the protective oxide layer on titanium.

Material Selection Based on Corrosion Resistance

- **Tantalum and Zirconium**

✓ Tantalum is inert to all organic compounds at temperatures below 150 °C, but it is not resistant to hydrofluoric acid and sulfuric acid.

✓ Zirconium is resistant to mineral acids, solutions, molten alkalis, most organic solvents, and salts.

Material Selection Based on Corrosion Resistance

- **Tantalum and Zirconium**

✓ Zirconium has excellent resistance to oxidation up to 400 °C in air, vapor, CO_2, SO_2, and O_2. However, it is attacked by HCl, moist chlorine, iron chloride solution, aqua regia (a mixture of concentrated HNO_3 and concentrated HCl in a 1:3 volume ratio), and cupric chloride.

✓ Although the use of these two metals is not primarily economical, they are the only materials resistant in some applications.

Material Selection Based on Corrosion Resistance

- **Glassy Metals**

✓ Glassy metals or amorphous alloys obtained by rapidly cooling the melt, which lack a crystalline structure, have a corrosion resistance close to that of tantalum and noble metals. An example of their combination is as follows:

- 8-20% Cr, 13% P, 7% C and the rest Fe
- 10% Cr, 5-20% Ni, 13% P, 7% C and the rest Fe

Material Selection Based on Corrosion Resistance

- **Glassy Metals**

✓ These materials are simply passivated and with 8% chromium, they have better corrosion resistance than conventional stainless steels. The pitting resistance of these glassy metals is equal or even better than high nickel and titanium alloys.

Material Selection Based on Corrosion Resistance

- **Plastics and Composites**

✓ Due to their excellent corrosion resistance, plastics and polymer composites have replaced metals in many applications (such as car bumpers, fenders, and other car body components).

✓ Absorption of moisture in some plastics causes a decrease in strength and electrical resistance, as well as causing swelling.

✓ Among thermosetting plastics, epoxies have the best combination of corrosion resistance and mechanical properties.

Material Selection Based on Corrosion Resistance

- **Plastics and Composites**

✓ Polymers are dissolved in organic solvents. Generally, crystalline thermoplastics such as Teflon and nylons are more stable than amorphous types (such as polycarbonates). Fluorocarbonates such as polytetrafluoroethylene (PTFE) are among the most chemically neutral engineering materials that are neutral to all industrial chemicals and resistant to hot nitric acid, hydrofluoric acid and most organic solvents.

✓ Other thermoplastics such as polystyrenes and polyphenylene sulfides also have excellent resistance to chemicals even at relatively high temperatures.

Material Selection Based on Corrosion Resistance

- **Ceramic Materials**

✓ Most ceramic materials have good chemical resistance to most substances except hydrofluoric acid.

✓ Glazes containing borosilicate and silicate glasses, along with fluxing agents used to facilitate particle bonding, have excellent corrosion, and are used to protect the surfaces of steels and cast irons.

Material Selection Based on Corrosion Resistance

- **Ceramic Materials**

✓ Glasses are among the materials with very high chemical stability and are resistant to water, aqueous solutions, most acids, alkalis, and salts. However, different types of ceramics have significantly different performance in various environments. For example, boron silicates and silica glasses have much better resistance to boiling water and dilute acidic solutions compared to lead-containing alkaline glasses and lime-soda glasses.

Material Selection Based on Corrosion Resistance

- **Other Protection Methods**

✓ In some cases, no material economically provides a combination of corrosion resistance and other required properties simultaneously. In such cases, an inexpensive material with desired physical and mechanical properties can be used, and its surface can be coated with a suitable protective layer.

✓ This protection can be based on sacrificial, inhibiting, corrosion-resistant, barrier-forming, or cathodic protection coatings.

Material Selection Based on Corrosion Resistance

- **Other Protection Methods**

✓ Protective coatings against corrosion can be various types of noble metals (nobler than the base metal), such as coating the surface of steel with tin. However, if a crack or hole is formed in the coating, the intensity of corrosion of the base metal is more severe than when it is without a coating. If the coating metal is anodic compared to the base metal, by forming a galvanic cell, the coating dissolves anodically and the base metal remains protected from corrosion. Aluminum, zinc, and cadmium coatings on steel are based on this principle.

Material Selection Based on Corrosion Resistance

- **Other Protection Methods**

✓ Organic coatings (like most polymers such as epoxy, polyamide, vinyl, etc.) and glass or porcelain glazes (mineral coatings) like cobalt and nickel oxides for steel and lead oxides for cast iron are other types of protective coatings against corrosion.