Advanced Corrosion

Number of Credits: 2 units

Course Type: Theoretical

Overall Course Objective:

In the Advanced Corrosion course, the importance of metal corrosion is first presented, followed by a detailed examination of thermodynamic and electrochemical kinetics of corrosion. Subsequently, various forms of corrosion are evaluated, and finally, after a comprehensive study of the passivity phenomenon, pitting corrosion is extensively analyzed.

Course Outline:

1- Electrochemical Thermodynamics of Corrosion: Electrode potential and Gibbs free energy, emf series, concentration effects on electrode potential, determining reaction direction through Gibbs free energy calculation, Pourbaix diagrams (potential/pH), applications and limitations, examining Pourbaix diagrams for different metals (including iron, aluminum, chromium, nickel, titanium, zirconium, etc.).

2- Electrochemical Kinetics of Corrosion: Faraday's law, exchange current density, activation polarization, concentration polarization, Evans diagrams, mixed potential theory, potential and current density of corrosion, effects of exchange current density, effects of oxidizing agents, effects of solution velocity, polarization curves, cathodic and anodic polarization, laboratory methods for studying corrosion, galvanostatic circuits, design of polarization cells, electrolyte impedance, rotating disk electrode for concentration polarization, electrochemical impedance spectroscopy studies.

3- Passivity: Passive films, active/passive corrosion behavior, effects of oxidizing agents, effects of solution velocity, effects of temperature and electrolyte pH, passivation criterion, laboratory methods for studying passivity, galvanostatic anodic polarization for active/passive alloys, potentiodynamic and potentiostatic methods, effects of different variables on electrochemical behavior and corrosion rate of passivating metals, properties of passive films, kinetics of passive film growth.

4- Pitting Corrosion: Factors and conditions causing pitting corrosion, mechanism of pitting corrosion, pitting corrosion assessment, measurement of metal susceptibility to pitting corrosion, methods for measuring pitting potential (including measurement of current density over time at a constant potential, measurement of potential over time at a constant current), critical temperature measurement experiment for pitting corrosion initiation, pit nucleation sites, role of sulfide in pit nucleation, pitting corrosion in plain carbon steel, pitting corrosion in stainless steel, effect of sulfide inclusion on the corrosion of iron, nickel, and steel in acidic electrolytes, investigation of sulfides' role in pit nucleation, boundary effects, theories of pitting corrosion (including adsorption theory, penetration and anion migration theory, mechanical/chemical theory, and localized acidification theory).

5- Examining other types of localized corrosion, including crevice corrosion, galvanic corrosion, and dezincification in alloys, with a focus on dezincification (process, influencing factors, and corrosion mechanism).

Cathodic and Anodic Protection

Number of Credits: 2

Course Type: Theoretical

General Objective of the Course:

Familiarizing students with the principles and criteria of cathodic protection, examining cathodic protection systems, sacrificial anode systems (galvanic), impressed current systems, stray currents caused by cathodic protection installations, and anodic protection.

Course Outline:

1- Cathodic Protection Methods: Definition, history, electrochemical functioning of cathodic protection, cathodic protection using sacrificial anodes, cathodic protection using impressed current, cathodic protection criteria, selection of system types, size and spacing of cathodic protection systems, remote grounds, near grounds, electrical obstacles, and cathodic protection, effects of excessive cathodic protection on pipelines, cathodic protection efficiencies.

2- Pipeline Coatings: Role of coatings in cathodic protection, types and characteristics of pipeline coatings, inspection methods for coatings, tape coatings, extruded polyolefin coatings, fusion-bonded epoxy coatings, multilayer coatings, cathodic disbondment.

3- Cathodic Protection Criteria: Potential Criterion with Cathodic Protection, Polarized Potential Criterion, criteria for steel and cast iron structures, Potential Displacement Criterion, criteria for aluminum and copper pipes, examining the influence of microbiological corrosion on cathodic protection criteria.

4- Survey Methods and Evaluation Techniques: Data collection, survey methods for cathodically protected pipelines, various measurement methods, measurement of remote and close potentials, measurement of pipeline currents, measurement of soil resistivity, electrochemical soil analysis, test for determining the required current for cathodic protection, microbiological corrosion testing, and survey data recording.

5- Cathodic Protection Using Sacrificial Anodes: Types of sacrificial anodes, applications of sacrificial anodes, specifications of magnesium, zinc, and aluminum anodes, backfill for anodes, calculation of anode life and installation details of sacrificial anodes, determining backfill locations, anodic bed design, sacrificial anodic systems, design and installation of deep anode cathodic protection systems.

6- Cathodic Protection Using Impressed Current: Types of rectifiers, selection of rectifier capacities, anodic bed equipment for impressed current systems, types of anodes, backfill materials, types of cables and connections in impressed current systems.

7- Design, Installation, and Evaluation of Cathodic Protection Systems and problem-solving.

8- Stray Currents: Stray currents caused by cathodic protection installations, interference effects, interference testing, various methods for reducing stray current interference, use of current transfer cables, use of sacrificial anodes, use of electrical barriers, and pipeline remediation.

9- Anodic Protection: History, principles of anodic protection, passivation of metals and alloys, comparison of anodic protection principles with cathodic protection, applications of anodic protection, necessary equipment for anodic protection including cathodes, reference electrodes, potential control devices, and power sources, principles of anodic protection design, economic considerations of anodic and cathodic protection, practical examples of anodic protection applications.

10- Cathodic Protection in Seawater: Overview of cathodic protection systems in seawater, comparison of cathodic protection systems in seawater and soil, examination of calcareous deposits on steel structures with the application of cathodic protection in seawater.

Corrosion Protection Lab

Number of Credits: 1

Course Type: Experimental

Prerequisite: Cathodic Protection and Anodic Protection

General Objective of the Course:

Conducting cathodic protection experiments in simulated soil and seawater, performing coating experiments and evaluating coating quality, examining the effects of inhibitors on steel corrosion, and conducting anodic protection experiments.

Course Outline:

- Cathodic protection of steel in soil.
- Cathodic protection of steel in simulated seawater.
- Investigating the effects of inhibitors on reducing steel corrosion by electrochemical impedance spectroscopy method.
- Phosphating and chromating of steel.
- Salt spray test and the effect of moisture on coatings.
- Aluminum anodizing.
- Measurement of soil resistivity by using the four-pin method.
- Anodic protection of steel in acid, applications and limitations.
- Evaluating the quality, thickness, adhesion and other properties of organic coatings.

Oxidation and High Temperature Corrosion

Number of Credits: 2

Course Type: Theoretical

General Objective of the Course:

Introducing the phenomena of high-temperature corrosion including oxidation and hot corrosion, explaining the fundamentals, mechanisms, and factors influencing the process, as well as methods to measure the material resistance against high-temperature corrosion. Furthermore, elucidating the principles and factors affecting oxidation phenomena and methods to improve material resistance against these kinds of corrosion.

Course Outline:

- Introduction to oxidation and high-temperature corrosion phenomena
- Evaluation methods for oxidation
- Examination of oxidation rate laws
- Investigation of methods for studying the morphology of oxide layers
- Thermodynamic principles in high-temperature oxidation studies
- Oxidation kinetics
- Sudden oxidation
- Oxidation of pure metals
- Oxidation of alloys (preferential oxidation, internal oxidation, destructive oxidation, formation of complex oxides)
- Effect of impurities on metal oxidation
- Structure of oxides and ion migration mechanism
- High-temperature corrosion (types, stages, mechanisms, study methods, control methods, and materials' resistance against high-temperature corrosion)
- Mechanical aspects of oxidation (sources of mechanical and thermal stresses in oxides, methods to improve resistance against oxidation, oxidation of ceramic materials)
- Other high-temperature phenomena (sulfidation, carburization, decarburization, nitridation, etc.) and their control methods.

Materials Characterization Techniques

Number of Credits: 2

Course Type: Theoretical

General Objective of the Course:

Identification and characterization of material structures, including determining the size and morphology of phases, examining crystal defects and phases, determining the atomic arrangement of crystalline and non-crystalline phases, chemical analysis using electron microscopy and related devices, X-ray diffraction, and familiarity with various material analysis methods.

Course Outline:

X-ray: Characteristics, generation, types, absorption and filtering, X-ray scattering phenomenon by the atomic arrangement of the material, X-ray spectroscopy, X-ray scattering methods, coefficients and factors affecting the scattering intensity, determination of material crystalline structure from the scattering pattern, quantitative and qualitative measurements of X-ray diffraction patterns.

Scanning Electron Microscopy: Magnification, resolution, and depth of field, signals and image contrasts, environmental microscopy, low vacuum microscopy, sample preparation.

Transmission Electron Microscopy: Bright and dark field images and electron diffraction, phase and domain contrasts, point, ring, and convergent electron diffraction patterns and their interpretation, the effect of deposition shape on electron diffraction pattern, preparation of thin foil samples, crystal defects contrasts, investigation of crystalline phase relationships, high-resolution or lattice contrast, determination of chemical composition using energy-dispersive spectroscopy, kinematic and dynamic theories of scattering, and interpretation of image features based on them.

Electron Spectroscopy, basic concepts, surface analysis, spectroscopy symbolization, X-ray photoelectron spectroscopy symbolization, Auger electron spectroscopy, Auger scanning microscopy, depth analysis in electron spectroscopy, a comparison between X-ray photoelectron spectroscopy and Auger electron spectroscopy/scanning Auger microscopy, surface analysis and characterization equipment, design of electron spectrometers, vacuum system, X-ray sources in X-ray photoelectron spectroscopy, electron gun compensation in Auger electron spectroscopy, electron sources, thermionic emitter, field emitter, cold field emitters, comparison of electron sources used for Auger spectroscopy, analyzers in electron spectroscopy, cylindrical mirror analyzer, hemispherical sector analyzer, transmission lens, detectors, channel electron multipliers, channel plates, small spot X-ray photoelectron spectroscopy defined with a lens, small spot surface analysis defined with a source, imaging and mapping in X-ray photoelectron spectroscopy, lateral resolution in small spot X-ray photoelectron spectroscopy, fixed-angle X-ray photoelectron spectroscopy, electronic spectrum, unexpected shapes in electronic spectra, information on the state of matter, electron excitation in electron spectroscopy, Auger parameter, state maps, plasmon, factors affecting quantitative determination in electron spectra, quantitative investigation in X-ray photoelectron spectroscopy, quantitative investigation in Auger electron spectroscopy, depth profiling of chemical composition, non-destructive methods for depth profiling, elastic scattering, recent advances in fixed-angle X-ray photoelectron spectroscopy, changes in depth analysis with electron kinetic energy, depth profiling by ion sputtering, scattering process, factors affecting depth resolution, ion beam specifications, beam quality, beam impurities, depth information, surface initial roughness, applied roughness, selective spectroscopy, re-deposition of materials under investigation, calibration, design of an Auger gun, cold cathode Auger gun, electron guns for electron impact, dual plasma gun, liquid metal guns, application of electron spectroscopy in materials science, interfacial separation, electronic structure of metallic alloys, ceramics and catalysts, semiconductors and microelectronics, examination of semiconductor components by electron spectroscopy, comparison of X-ray photoelectron spectroscopy and Auger electron spectroscopy with other analytical techniques, X-ray analysis in electron microscopy, Auger spectroscopy, electron spectroscopy for chemical analysis, secondary ion mass spectrometry, photoelectron spectroscopy.

Mechanical Aspects of Corrosion

Number of Credits: 2

Course Type: Theoretical

General Objective of the Course:

Investigating the effect of corrosion on the mechanical properties of materials, such as stress, fatigue, erosion, wear, and fracture.

Course Outline:

1- Introduction to fracture, stress concentration at crack tips.

2- Fundamentals of fracture mechanics: Griffith's theory, stress analysis at cracks, relationship between the release of energy and stress fields, Westergaard's theory, analysis of stress intensity, estimation of the plastic zone at crack tips, fracture modes, plane stress versus plane strain, fracture toughness tests for engineering materials, fracture toughness determination methods, and elastic-plastic analysis.

3- Stress Corrosion Cracking (SCC): Introduction, approach and considerations from a fracture mechanics perspective, testing methods, K1SCC as a material property, accuracy of K1SCC data, general considerations, crack growth rate tests, chemical composition effects and applied potentials.

4- Fatigue Fracture: Introduction, general behavior, fatigue behavior below K1SCC, fatigue mechanisms in corrosive environments, crack growth mechanisms, crack initiation, fatigue in corrosive environments, the effect of corrosive environments on Δk_{th} and assisting parameters.

5- Hydrogen Embrittlement: Introduction, general behavior, testing methods, lifetime and crack length calculations.

6- Erosion Corrosion: Introduction, general behavior, influential factors and mechanisms, simultaneous mechanical erosion-corrosion tests.

7- Wear Corrosion: Process, influential factors and mechanisms, simultaneous mechanical wear-corrosion tests.

8- Cavitation: Process, variable effects, and mechanisms. Standard methods for investigating the mechanical aspects of corrosion.

Advanced Electrochemistry

Number of Credits: 2

Course type: Theoretical

Overall Course Objective:

Exploring the fundamentals of electrochemistry and its relevance to advanced topics in the field of electrochemical corrosion processes.

Course syllabus:

1- Electrolytes: Ion mobility, conductivity and specific conductivity of electrolytes, molar conductivity and Kohlrausch's law, ion mobility and its relationship with specific conductivity, Debye-Hückel equation for measurement and its applications, measurement of transport number, interaction between ions and solvent molecules, ion-ion interaction, electrophoretic effect, ideal and non-ideal solutions, ionic strength.

2- Principles and basic laws of electrochemistry: Differentiation between chemical and electrochemical reactions, cathodic and anodic reactions, principles of corrosion electrochemistry, correlation between the double electric layer chemistry and electrical current, electrochemical corrosion diagrams (Evans diagrams), electrochemical tests, the influence of various variables on corrosion test results, correction of electrochemical corrosion results, result scattering.

3- Electrolysis and electrodes: Electrolysis theory, practical aspects of electrolysis, types of electrodes (metal/ metal ion, gas, composite), reference electrodes and their applications, electrochemical characteristics for selection and design of reference electrodes, electrode/electrolyte junction, electrode potentials, surface adsorption, multilayer adsorption, different models of double electric layer (Helmholtz, Gouy-Chapman, Stern, Bockris), potential and concentration changes in the double layer, electrode resistance and capacitance, equivalent circuit, zero charge point (PZC), surface tension and electrocapillarity, electrical charge transfer rate.

4- Electrochemical potential: Reversible potential and standard potential, types of electrochemical cells, Nernst equation, calculation of potential for various reference electrodes.

5- Types of polarization: Activation polarization, concentration polarization, ohmic polarization, Tafel polarization (principles, plotting methods, diagram structure, determination of slopes, determination of corrosion rate, errors), potentiodynamic and potentiostatic polarization (principles and rules, different regions on the curves, plotting method, effect of sweep rate on curve behavior, obtaining corrosion behavior).

6- Linear polarization and its effect on corrosion behavior: Description of linear polarization curves, advantages and disadvantages of linear polarization compared to other methods.

7- Electrochemical impedance spectroscopy (EIS): Basic principles including an introduction to direct and alternating currents, types of representation formats of impedance curves such as Nyquist, Bode, and Bode phase, different time constants and sources of time constants, employed equivalent circuits and description of equivalent circuits, application of electrochemical impedance spectroscopy in corrosion studies such as coating resistance, inhibitors, application of electrochemical impedance spectroscopy in various electrochemical reactions such as electrocatalytic reactions.

Materials Characterization Techniques Lab

Number of Credits: 1

Course type: Experimental

Prerequisite: Modern Methods of Materials Study

Overall Course Objective:

Performing and analyzing practical experiments related to the identification of material structures (phases, crystal structures, and crystal defects) using X-ray Diffraction (XRD), electron microscopes, and related chemical analysis instruments.

Course syllabus:

1- XRD of different samples.

2- Study of fracture surfaces with SEM.

3- Study of corrosion surfaces and/or coatings with SEM.

4- Surface topography of wear.

5- Material analysis using EDS and EPMA.

6- Investigation of surface morphology of the coatings.

7- Electron diffraction for crystal lattice and crystallographic orientations.

8- Coating thickness measurement with SEM.

9- Material analysis using RBS.

10- Preparation of TEM samples using various methods.

11- Study of selected samples with TEM microscopy.

12- Surface analysis with Auger spectroscopy and SIMS.

Corrosion Inhibitors

Number of Credits: 2

Course type: Theoretical

Prerequisite: Advanced Corrosion

Overall Course Objective:

Investigating corrosion inhibitors, their performance, and mechanisms in different environments.

Course syllabus:

Definition of inhibitors, types of inhibitors, various environmental effects on corrosion inhibition (temperature, concentration, fluid velocity, etc.), inhibition mechanisms in neutral and acidic environments, passivation phenomenon in metals, corrosion inhibition in drinking water and industrial water (open, closed, and once-through cooling systems), inhibitors in the petroleum, gas, and petrochemical industries, inhibition in paints and oils, inhibitors for heavy fuel (high-temperature corrosion control), atmospheric corrosion inhibition during short and long-term shutdowns (wet, dry, and neutral gases), chemical cleaning in industrial equipment (acid cleaning and alkaline cleaning), selection of cleaning agents and inhibitors for chemical cleaning, sampling of deposits, formation of protective layers after acid cleaning, compliance with necessary guidelines during chemical cleaning, corrosion and fouling inhibition in steam boilers and feedwater systems (corrosion control of iron and copper tubes in heat exchangers), inhibition for galvanic systems, inhibition for localized corrosion control, inhibition for pitting corrosion control, inhibition for non-ferrous metals (copper, aluminum, zinc, lead, etc.), microbiological corrosion and its control using inhibitors, inhibition testing methods (weight loss, polarization methods, rotating disk methods, AC impedance electrochemical methods).

Advanced Thermodynamics and Kinetics of Corrosion

Number of Credits: 2

Course type: Theoretical

Overall Course Objective:

Introduction to the fundamentals, principles, and relationships of thermodynamics and kinetics in corrosion and materials science.

Course syllabus:

Formation of cells, concentration cells, temperature coefficient of cells, thermal effects, principles of Pourbaix diagrams and related issues, thermodynamic analysis of corrosion processes and materials protection, thermodynamics principles in high-temperature oxidation studies, surface thermodynamics, surface energy and surface tension, surface energy asymmetry, interfacial and chemical separation, structural separation at interfaces, thermodynamics of crystal defects.

A review of thermodynamics of materials, including relationships between thermodynamic functions, thermodynamics of solutions, calculation of molar quantities and activity, types of solutions, Gibbs-Duhem equation in binary and ternary systems, changing the standard state, dilute multi-component solutions.

Molar free energy diagrams, partial molar and activity diagrams, their relationship with phase diagrams of binary systems, phase equilibria, statistical thermodynamics, entropy and Boltzmann equation, types of entropy.

Semi-empirical models and other models for solutions, molecular theory, ionic theory, short-range order and long-range order in solutions, thermodynamics of aqueous solutions, chemical and electrical energy relationship, the effect of concentration on electromotive force.

A review of electrochemical kinetics laws, reaction rate, the effect of temperature on reaction rate, complex reaction kinetics, reversible reactions, chemical kinetics in solution, mass transfer models (diffusion and conduction), ion reactions, ion separation reactions, the effect of solvent on reaction rate, the effect of ionic strength on reaction rate, catalysts, electron transfer kinetics, electrode reaction kinetics.

Conversion and Organic Coatings

Number of Credits: 2

Course type: Theoretical

Overall Course Objective:

Investigating corrosion protective coatings and comparing the capabilities of coatings in protecting substrates against corrosion.

Course syllabus:

Introduction to different types of coatings, formulation and fabrication of coatings, methods of applying coatings on surfaces, applications of coatings, transformative coatings, organic coatings, paints, memory coatings, plasma-assisted synthesis of coatings, fundamentals of plasma electrolytic oxidation, the use of plasma electrolytic oxidation in surface engineering, chemical and physical aspects of plasma electrolytic oxidation, characteristics and effects of current, voltage, nitrogen, plasma electrolyte carbonization, monitoring principles in saturated plasma electrolytic, electrolyte selection for the plasma electrolytic process, microhardness of the layer, mechanical properties of transformative coatings, anodizing, phosphate coatings, chromate coatings, sulfurizing process, nitrocarburizing process, microstructure analysis of produced films, multifunctional nanostructured coatings, multilayer coatings, novel processes for industrial applications of tribological multifunctional coatings, preparation and properties of nanostructured coatings, case studies of coatings, microstructure analysis, microhardness analysis, phase analysis, wear properties analysis, corrosion performance analysis of coatings, protective properties analysis of coatings, physical properties analysis of coatings, mechanical properties analysis of coatings, hardness, toughness, residual stress, adhesion, hard coatings and superhard coatings, microstructure design, specification determination, composition, topography, grain size, preferred orientation, lattice parameter, hard and tough nanocomposite coatings, aluminum-rich amorphous carbon, tribology, dry condition tribology, lubricated condition tribology, thermal stability and oxidation resistance.