National Technical University of Ukraine
"Kyiv Polytechnic Institute"
Welding Faculty
www.interweld.kpi.ua

Module 1: Welding processes and equipment

1.1 General introduction to welding technology

- History
- Definitions
- Schematic presentation of welding processes
- Terminology
- Picture and brief description with characteristics
- Applicability of the most common welding processes
- General applications for welding
- Abbreviations used for welding processes
- Hints in use for welding processes
- Classification of welding processes (IIW, ISO, CEN and national standards)

1.2 Oxy-gas Welding and related processes

- Process principles
- Range of Application
- Types of Flames
- Characteristics of fuel gases, (acetylene, propane, etc.)
- Combustion reactions
- Temperature distribution effects
- Equipment
- Acetylene cylinder component parts
- Fuel gas generation
- Handling and storage of gases
- Typical joint design for welding
- Methods of welding techniques, rightward, leftward
- Standards for filler materials
- Welding applications, typical problems and imperfections
- Special techniques and their methods of use (preheating, straightening, cleaning, etc.)
- Health and safety issues specific to the process

1.3 Electrotechnics, a review

- Basics of electricity and electronics (define current, voltage and resistance)
- Ohm's Law
- Parallel and serial circuits
- Direct current (DC), polarity, alternating current (AC)
- Magnetism in welding
- Capacity, condenser
- Transformer, and rectifying bridge (half wave and full wave rectification)
- Transistor, thyristor, Inductance, inductors
- Hazard
- Health and safety

1.4 The arc

- Arc physics (producing an electric arc, the main arc areas, stability of the arc)
- Voltage distribution across the arc

- Heat generation at the cathode and anode
- Polarity and arc characteristics in AC and DC and its control for the key welding processes
- Influence on the welding process
- Temperature distribution in the arc and effects
- Influence of the magnetic fields on the arc (why, how to solve)
- Limits of application

1.5 Power sources for arc welding

- Power source classification, types and characteristics (static and generators, and each sub-group)
- Power source electrical characteristics (static and dynamic
- Relationship between static characteristic and welding process
- Control of the electrical static characteristic (flat and drooping)
- Arc stability for the main processes (MMA, TIG, MIG/MAG, SAW, PAW)
- The operation working point
- Inverter technology
- Power sources controlled by a CPU
- Stability of processes in AC and DC
- AC (sine wave and square wave) and DC power sources
- Open circuit voltage, short circuit current, power factor of transformers
- Duty cycle of a power source and typical values for the most common arc welding processes
- Voltage losses, relationship between welding current value and cable section
- Pulse welding techniques
- Arc striking methods and devices, slope up and down, pre- and post-flow
- Current and voltage setting (electromagnetic and electronic devices)
- Standards related with welding power sources and their requirements

1.6 Introduction to gas shielded arc welding

- Physical phenomena
- Operating principles of TIG, MIG/MAG and flux-cored
- Shielding gases (inert, active) and their effect on arc characteristics
- Handling and storage of gases
- Filler materials
- Standards (International and National) for shielding gases and filler materials

1.7 TIG Welding

- Power source characteristics
- Methods for arc ignition and necessary equipment
- Equipment and accessories: torches, gas lens, control panel, up and down slope, pulse techniques
- Effect of current type and polarity: DC(+), DC(-) and AC
- Specific requirements for different materials, e.g. Al
- Consumables: shielding gases, filler materials, electrodes
- Welding parameters: current, voltage, travel speed, gas flow rate

- Joint preparation: typical joint design for welding, fit-up, cleaning
- Welding procedures
- Special techniques: spot-welding, key-hole, hot-wire, orbital welding, tube to tube and tube to sheet , and others
- Standards for filler materials, electrodes, and gases
- Welding applications, typical problems and how to solve them
- Health and safety issues specific to the process

1.8 MIG/MAG and Flux Cored Arc Welding

- Power source characteristics for conventional process and CPU controlled power sources
- Effect of current type and polarity
- Equipment and accessories: torches, wire feeders, hose assembly, control panel
- Metal transfer modes (dip, globular, spray, pulsed and rotating), and their Application
- Welding parameters and settings: current, voltage, travel speed, gas flow rate, etc
- Consumables: shielding gases, filler materials (solid and flux cored wires), and their combinations
- Joint preparation: typical joint design for welding, fit-up, cleaning
- Welding procedures
- Special techniques: electro-gas welding, high efficiency processes
- Standards for filler materials, and gases
- Welding applications, typical problems and how to solve them
- Health and safety specific to the process

1.9 MMA Welding

- Process principles and arc characteristics
- Effect of current type and polarity
- Power source characteristics applicable to MMA (open circuit voltage, static and dynamic characteristics, types of current, arc striking methods)
- Equipment and accessories
- Process application range, typical problems and how to solve them
- Covered electrodes (functions of the coating and rod, types of electrodes, slag-metal and gas-metal covered reactions)
- Production of electrodes (how, typical defects)
- Handling and storage of electrodes (storage environment, redrying)
- Electrode classification (International and national standards)
- Selection of covered electrodes for applications
- Welding parameters: current, voltage, run out length, etc
- Joint preparation: typical joint design for welding, fit-up, cleaning, welding position
- Relationship between electrode diameter and current range, rod material, electrode length and welding position
- Welding procedures
- Special techniques (gravity welding, vertical down welding, on-site welding
- Health and safety specific to this process

1.10 Submerged-Arc Welding

- SAW process principles and arc characteristics

- Effect of current type and polarity
- Power source characteristics applicable to SAW (open circuit voltage, static and dynamic characteristics, types of current, arc striking methods)
- Equipment and accessories
- Process application range, typical problems and how to solve them
- Consumables (functions of the flux and wire -solid or flux cored-, types of flux and wire, wire-flux combination, slag-metal and gas-metal reactions)
- Production of consumables (how, typical defects)
- Handling and storage of consumables (storage environment, re-drying)
- Consumable classification (International and national standards)
- Welding parameters: current, voltage, travel speed, type of flux and particle size, stick-out, etc
- Joint preparation: typical joint design for welding, fit-up, cleaning
- Relationship between the wire-flux combination and the characteristics of deposited material
- Welding procedures
- Single-wire and multi -wire techniques
- Special techniques (strip-cladding, iron-powder addition, cold and hot wire addition)
- Health and safety specific to SAW process

1.11 Resistance Welding

- Process principles and overview on types of processes (spot, projection, butt, seam, and flash)
- Joule effect and temperature distribution
- Equipment and accessories
- Process application range and typical problems (welding thin to thick material, welding of coated/ painted materials, welding dissimilar materials, mass effect, shunt effect, Peltier effect, resistance brazing)
- Electrodes (functions, types, shapes, material)
- Electrode classification (International and national standards)
- Welding parameters: current, pressure, time, type of current, pulse, etc
- Joint preparation: typical joint design for welding, fit-up, cleaning
- Relationship between welding parameters and the characteristics of the weld nugget
- Monitoring systems, process control, measuring
- Specific testing
- Welding procedures
- Health and safety specific to this process

1.12.1 Other Welding Processes – LASER; Electron Beam; Plasma

- Basic principles for all mentioned processes
- Heat generation for each type of process
- Equipment and accessories for each type of process
- Typical process applications and problems
- Consumables
- Welding parameters for each process
- Joint preparation: typical joint design for welding, fit-up, cleaning

- Relationship between welding parameters and joint configuration
- Comparison between high energy processes
- Health and safety specific to the processes
- Appropriate national and international standards for each process

1.12.2 Other Welding Processes, other than 1.12.1: electro-slag, friction; friction stir, magnetically impelled arc butt (MIAB); magnetic pulse welding, ultrasonic; explosive; diffusion; aluminothermic; high-frequency; stud, cold-pressure welding, hybrid processes, etc.

- Basic principles for all mentioned processes
- Heat generation for each type of process
- Equipment and accessories for each type of process
- Typical process applications and problems
- Consumables
- Welding parameters for each process
- Joint preparation: typical joint design for welding, fit-up, cleaning
- Relationship between welding parameters and joint configuration
- Comparison between high energy processes
- Health and safety specific to the processes
- Appropriate national and international standards for each process

1.13 Cutting and other edge preparation processes

- Survey of edge preparation processes
- Mechanical cutting
- Principles of flame and flame powder cutting, equipment, applications and auxiliaries
- Flame cutting parameters, edge quality, oxygen purity grades
- Materials suitable for flame cutting
- Basic principles of the various arc cutting processes (arc-air, carbon and metal-arc, oxy-arc cutting, gauging with carbon electrode) equipment and auxiliaries
- Materials suitable for arc-cutting, applications, cutting parameters for each process
- Fundamentals of plasma cutting, equipment and auxiliaries
- Materials suitable for plasma cutting, applications, cutting parameters, cutting gases
- Plasma cutting special applications (under water cutting, cutting with water vortex)
- Plasma gouging
- Fundamentals of electron beam drilling and LASER cutting, equipment, parameters, applications
- Fundamentals of water jet cutting, equipment, parameters, applications
- Fundamentals of arc gouging and flame gouging, parameters and applications
- Appropriate national and international standards for each process
- Health and safety

1.14 Surfacing and Spraying

- Working principles and applications for cladding techniques (rolling, explosive, strip, plasma-MIG, electroslag, LASER, etc)
- Working principles and applications of the spraying techniques (flame spraying with powder, flame spraying with wire, arc spraying with powder, arc spraying with wire, plasma spraying with powder, HVOF spraying)

- Equipment and parameters for each technique
- Surface preparation of the base material
- Spraying materials
- Sprayed layer structure, and substrate structure
- "Cold " and "fusion techniques"
- Applications and special problems
- Health and safety

1.15 Fully mechanised processes and robotics

- Survey of welding mechanisation for higher productivity
- Robotics, mechanisation, and automation: differences, advantages disadvantages and applications
- Robotics (on-line and off-line programming, simulation, flexible manufacturing systems)
- CAD/CAM systems
- Virtual factory (factory simulation)
- Seam tracking, types and typical applications
- Gas nozzle sensor, arc sensing, magnetic induction, vision system
- Narrow gap welding (SAW, MIG/MAG, TIG)
- Orbital welding (MIG/MAG, TIG)
- Application, typical problems and how to solve them
- Gases and filler materials (optimisation for mechanised welding)
- Health and safety
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1.16 Brazing and soldering

- Fundamentals of brazing and soldering (bonding mechanisms, surface tension, wetting, capillary)
- Survey of brazing and soldering techniques, equipment, range of applications
- Consumables and fluxes for brazing and soldering, types, applications, and main functions of the fluxes
- Materials suitable for brazing, brazing requisites
- High vacuum brazing, brazing under controlled atmosphere
- Braze welding (Arc and laser brazing)
- Survey of soldering techniques (dip, wave flow, vapour phase, soldering)
- Brazing and soldering advantages and disadvantages
- Applications and special problems
- Overview on standards
- Health and safety

1.17 Joining processes for plastics

- General information on materials and joining processes
- Study the operating principle for each type of process
- Hot plate welding, butt fusion, hot gas welding, extrusion welding, induction
- welding, resistance welding, implant welding, high frequency, friction,
- electro-fusion welding, ultrasonic welding, vibration welding, adhesive
- bonding
- Control of welding parameters, types of equipment, joint design

- Advantages and disadvantages
- Applications and typical problems and how to solve them
- Health and safety

1.18 Joining processes for ceramics and composites

- General information on ceramics and composites and typical joining processes
- General study of the operating principles for each process
- Advantages and disadvantages
- Applications and special problems

1.19 Welding laboratory

- Practical exercises showing the effect of each main welding parameter on the weld bead shape
- Discussion of results to help future evaluation and diagnosis
- Exercises should cover: MMA, TIG, MIG/MAG, Flux Cored wires, SAW, Oxy-gas
- Practical exercises showing the effect of each main cutting parameter on the cut surface
- Exercises should cover: Oxy-cutting, Arc-Air, Plasma, Arc-Cutting

Module 2: Materials and their behaviour during welding

2.1 Manufacture and designation of steels

- Introduction to metallurgy of steel making
- Steel making processes
- Special treatments
- Deoxidation
- Designation of steels
- Defects in steels

2.2 Testing Materials and the weld joint

- Review of destructive testing
- Testing welded joints (technological specimen)
- Destructive testing
- Tensile and bend tests
- Impact tests (ductile and brittle fracture, transition temperature)
- Hardness tests
- Special tests (CTOD, etc.)
- Fatigue tests
- Creep tests
- Corrosion tests
- Overview on related standards
- Laboratory exercises
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2.3 Structure and properties of pure metals

- Crystalline structures
- Crystal lattice structure types and imperfections
- Micro structures of metals

- Solid state transformation
- Elastic/plastic deformation
- Recrystallisation
- Cold and hot deformation
- Work hardening and strain aging
- Mechanical properties (influence of temperature, etc.)

2.4 Alloys and Phase Diagrams

- Pure metals and alloys
- Alloying elements
- Solidification
- Solid solution crystals
- Structure of alloys
- Type of structures
- Strengthening mechanisms (cold working, solid solution, precipitation hardening, grain size control, solid state transformation)
- Intermetallic compounds
- Ageing
- Basic types of phase diagrams (non-, fully- and partly soluble components)
- Fe-C equilibrium diagram
- Influence of alloy elements on the Fe-C equilibrium diagram
- Iron-alloys with closed gamma-loop, with broadened gamma-area
- The structure of castings
- Segregation and coring
- Mechanical properties
- Ternary diagrams

2.5 Iron – Carbon Alloys

- Equilibrium and non equilibrium transformations
- Time-temperature-transformation (TTT) diagrams
- Different types of TTT diagrams (isothermal, continuous cooling, TTT diagrams for welding)
- Influence of alloying elements
- Carbide forming elements
- Control of toughness
- t8/5 concept

2.6 Heat treatment of base materials and welded joints

- Normalising
- Hardening
- Quenching and Tempering
- Solution annealing
- Homogenisation
- Stress relieving (PWHT)
- Recrystallisation annealing
- Precipitation hardening

- Heat treatment procedures
- Heat treatment equipment
- Regulations (codes and technical reports)
- Temperature measurement and recording

2.7 Structure of the welded joint

- Thermal field
- Equations for the heat distribution
- Heat input and efficiency of heat input
- Peak temperature
- Cooling rate and thermal cycle
- Dilution
- Weld metal
- Solidification of weld pool
- Structure of the weld
- Fusion line
- Heat-affected zone (HAZ)
- Microstructure of HAZ
- Grain growth and grain refinement
- Relationship grain size – toughness (equations from regression)
- Transition temperature
- Weldability (definitions)
- Single and multi -pass welding

2.8 Plain Carbon and Carbon-Manganese Steels

- Application of TTT diagrams
- Hardening effects
- Carbon equivalent
- Weldability
- Effects of multi-pass welding
- Structure of the weld and the HAZ
- Factors influencing cracking
- Relationship C% max – hardness
- Relationship Ceq – hardenability
- Determination of preheat and interpass temperature (diagrams)
- Weld – simulation (Weld thermal cycle simulation)
- Determination of the optimal heat input
- Influence of restraint
- Standards

2.9 Fine - grained steels

- Concept of grain refinement (micro-alloying elements, formation and dilution of particles)
- Effect on mechanical properties
- Normalised grades
- Quenched and tempered grades, high strength steels

- t 8/5 concept and weldability, preheat and interpass temperature
- Standards

2.10 Thermomechanically controlled process steels (TMCP -steels)

- Principles of treatment (controlled roll, accelerated cooling, direct quench, etc.)
- Chemical composition
- Mechanical properties
- High strength steels
- Applications
- Consequences for weldability
- Standards

2.11 Cracking phenomena in welded joints

- For C-Mn, low alloy, high alloy and stainless steels as appropriate:
- ***Cold cracking:***
  - Cracking mechanisms in weld metal and HAZ, causes and avoidance
  - Effect of hydrogen, microstructure and stress
  - Source and diffusion of hydrogen
  - Control of hydrogen
  - Susceptible microstructure and its control
  - Influence of alloying elements on susceptibility
  - Testing of cold cracking susceptibility
  - Effect of preheat
  - Effect of austenitic weld metal
- ***Hot cracking:***
  - Cracking mechanisms in particular in weld metal (solidification cracking, liquation cracking, etc.); causes and avoidance
  - Effect of alloy elements, heat input, bead shape, nugget shape
  - Control of hot cracking
  - Testing for hot cracking susceptibility
- ***Reheat cracking:***
  - Cracking mechanisms in weld metal and HAZ; causes and avoidance
  - Type of steels sensitive to reheat cracking
  - Effect of alloy elements, thermal cycles, stress
  - Cracking during heat treatment and multi -pass welding
  - Control of reheat cracking
  - Testing for reheat cracking susceptibility
- ***Lamellar tearing:***
  - Cracking mechanism; causes and avoidance
  - Effects of inclusions, joint configuration, stress, and fatigue
  - Control of lamellar tearing by material control and joint configuration
  - Testing for susceptibility, through-thickness properties
  - Steels with increased resistance to lamellar tearing

2.12 Application of structural and high strength steels

- Bridges

- Cranes
- Buildings
- Ships
- Pipelines
- Pressure vessels
- Automotive equipment
- Low temperature applications
- Standards

2.13 Low alloy steels for cryogenic applications

- Survey/list of types of cryogenic steels (including 9% Ni)
- Effects of nickel on low temperature properties of low alloy steels
- Applicable welding processes
- Filler materials .problems and precautions
- Properties and application of various types of cryogenic steels
- Controlling the quality of the welded joint
- Standards on low temperature steels and consumables

2.14 Low alloy creep resistant steels

- Mechanism of creep failure
- Testing of creep resistance
- Creep sensitivity testing
- Temper embrittlement, e.g. step cooling test
- Remaining life prediction
- Oxidation resistance
- Survey of types of creep/heat resistant steels
- Applicable welding processes
- Filler materials - special chemical requirements for creep resistance
- Welding problems and precautions
- Controlling the quality of a welded joint
- Standards

2.15 Introduction to corrosion

- Fundamentals of electrochemistry
- Redox potential
- Passivation
- Overall corrosion
- Differential aeration
- Cathodic, anodic protection
- Types of corrosion (intercrystalline, transcrystalline, knife-line attack pitting, crevice, and stress-corrosion)
- Pickling and passivating
- Corrosion testing
- Demonstrations for IWE - 2 hours from 6
- Demonstrations for IWT - 1 hour from 2
- Demonstrations for IWS and IWP - 0 hours

2.16 High-alloyed (stainless) steels

- Effect of alloying elements
- Systems Fe-Cr, Fe-Ni, Fe-Cr-Ni
- Austenite and ferrite formers
- Influence of nitrogen
- Cr- and Ni-equivalent
- Schaeffler diagram, DeLong and other constitution diagrams
- t 12/8 weldability concept
- Measuring of ferrite content
- Survey on stainless steels (fully austenitic, ferrite-containing steels, ferritic, martensitic, duplex stainless steels, chemically resistant, creep resistant, heat resistant steels, cryogenic use)
- Knife-line attack
- 475 °C-brittlement
- Weld decay (intergranular corrosion)
- Pitting Index
- Applicable welding processes
- Types of filler materials
- Shielding and backing gases
- Welding of stainless steels
- Details of joint design
- Heat treatment
- Post-weld heat treatment (PWHT)
- Passivation
- Standards

2.17 Introduction to wear

- Different types of wear (hydrodynamic friction, reaction, layer wear, adhesive wear, abrasive wear, fatigue wear, fretting, erosion, cavitation, impact, thermal, dynamic)
- Buttering
- Wear tests

2.18 Protective layers

- ***Cladding****:*
  - Reasons for cladding
  - Processes for cladding (dilution)
  - Joining clad steels
  - Joint design and welding procedures in respect to the access to the joint
  - Applications
  - Standards
- ***Linings:***
  - Welding of linings
  - Joint design and welding procedures
- ***Surfacing****:*
  - Corrosion-resistant layers

  - Wear-resistant layers
- ***Coatings:***
  - Surface-coated steels
  - Galvanised steels (Si-content)
  - Painting
  - Problems of joining

2.19 High alloy creep resistant and heat resistant steels

- Creep resistance of high alloy steels
- Mechanism of heat resistance
- Types of creep resistant steels
- Types of heat resistant steels (austenitic, ferritic)
- Weldability and selection of consumables
- Application and special problems
- Standards

2.20 Cast irons and steels

- Survey of cast steels
- Survey of cast irons
- Applicable welding processes and procedures
- Weldability
- Filler materials
- Application and special welding problems
- Standards

2.21 Copper and copper alloys

- Survey on classification of copper and copper alloys
- Desoxidation and weldability
- Physical and mechanical properties
- Applicable joining processes (welding, brazing, soldering, diffusion welding)
- Filler materials
- Shielding and backing gases
- Application and special problems
- Standards

2.22 Nickel and nickel alloys

- Survey on classification of nickel and nickel alloys
- Applicable welding processes and filler materials
- Shielding and backing gases
- Welding problems (hot cracking) and prevention
- Quality control of the welded joint

2.23 Aluminium and aluminium alloys

- Survey on classification of aluminium and Al-alloys (pure, cold work alloys, heat treatable alloys)
- Weldability

- Joint preparation
- Applicable welding processes
- Oxide layer cleaning (cathodic cleaning, trailing and trailing shield)
- Filler materials (choice, storage and handling)
- Shielding and backing gases
- Welding problems, (HAZ softening, porosity and hot cracking, cracking diagrams distortion) and their avoidance
- Design details
- Application and special problems (lightweight structures, cryogenic use)

2.24 Other metals and alloys

- Titanium
- Magnesium
- Tantalum
- Zirconium
- Applicable welding processes and filler materials
- Special problems

2.25 Joining dissimilar materials

- Fundamentals
- Use of the Schaeffler / De Long diagram for welding dissimilar metals
- Choice of processes
- Effect of dilution
- Consumables
- Welding problems and measures, (formation of intermetallic compounds, carbon migration)
- In service failures (thermal fatigue, disbonding)
- ***Typical applications:***
  - Joining high alloyed steel and mild steel
  - Joining stainless steel and mild steel
  - Joining CuNi-alloys with mild steel/stainless steel
  - Joining Ni-alloys with mild steel
  - Joining stainless steel and copper alloys
  - Joining steel and Al / Al alloys
  - Joining Cu and Al / Al alloys
  - Joining Ni and Cu

2.26 Metallographic examinations

- Specimen preparation for micro and macro examination
- Macro and micro structure examination
- Micro chemical analysis of crystallographic structure
- Reference standards EN 1321, CR 12363

Module 3: Construction and design

3.1 Basic theory of structural systems

- Structural elements (cables, bars, beams, plates, slabs, shells)
- Theory of forces
- Combination and resolution of forces
- Equilibrium of forces and torques
- Bearings, constraints and basic types of connections
- Equilibrium of structural systems
- Statically determinate and indeterminate systems
- Stress in structural systems resulting from external actions
- Relationship between external loads and internal forces
- Calculation and determination of the internal forces and moments of simple statically determinate systems

3.2 Fundamentals of the strength of materials

- Types of stresses (normal stress, shear stress)
- Types of deformation (axial strain, shear strain)
- Stress-strain relationship, yielding theories
- Elastic and plastic deformation
- Young's modulus, shear modulus, transverse contraction coefficient
- Characteristic material properties
- Different stresses resulting from internal forces and moments
- Different types of section properties
- Calculation of section properties
- Calculation of stresses

3.3 Welded Joint design

- Introduction (importance of welding joint design and grove shapes, influence on welding stresses and distortion)
- Types of welded joints (ISO 9692 series, EN 14324 brazing)
- Importance of weld joint design and groove shapes, types of welded joints, design of welded joints
- Classification of groove shapes (by material type, thickness, welding process, accessibility)
- Tolerance requirements (ISO 13920)
- Welding symbols on drawings, symbols for groove shapes
- Symbolic representation of welded, brazed and soldered joints according to ISO 2553
- National Standards

3.4 Basics of weld design

- Types of stresses in welded joints (nominal stress, hot spot stress, notch stress)
- Stresses in butt welds, stresses in fillet welds
- Calculation of section properties of welded joints
- Determination of nominal stresses in single welded joints
- Determination of reference values of stresses due to multi-axial stressing
- Determination of design resistance of arc-welded and resistance-welded joints
- Worked examples of calculation of nominal stresses in welded joints

3.5 Behaviour of welded structures under different types of loading

- Static strength
- Elevated temperature strength
- Low-temperature strength
- Creep resistance
- Impact behaviour
- Influence of notches and weld defects
- Types of fracture (ductile fracture, fatigue fracture, brittle fracture, lamellar tearing)
- Selection of steel quality groups
- Typical data for common steels
- Use of standards and specifications

3.6 Design of welded structures with predominantly static loading

- Steel constructions including lightweight structures
- Structural details e.g. (stiffeners, knots, columns, base- and cap-plates, reinforced structures, supports, frame-corners, frame structures, trusses, nodal joints, weld connections, braces / bracing, lattice work structures, etc.)
- Use of different types of welds related to joint types
- Use of standards and specifications
- Worked examples

3.7 Behaviour of welded structures under dynamic loading

- Types of cyclic loading
- Statistical stress analysis on real structures
- S-N diagram
- Stress collective
- Fatigue strength (low cycle, and others)
- Effect of mean stress
- Effect of stress range
- Stress distribution
- Influence of notches
- Influence of weld defects
- Fatigue improvement technique (needle peening, TIG dressing, burr grinding, hammering, stress relieving, etc.)
- Standards
- Palmgren-Miner rule
- Classification of weld joints

3.8 Design of dynamically loaded welded structures

- Range of application: bridges, cranes, machines, ships and offshore constructions, chimneys, towers and masts, vehicles (cars, trucks, railway vehicles) etc
- Acceptance criteria
- Use of standards and specifications
- Worked examples

3.9 Design of welded pressure equipment

- Construction of boilers, pressure vessels, pipelines, etc
- Calculation (formulae) of the welds
- High and low temperatures applications
- Details of design (flanges, nozzles, shells, compensating plates etc.)
- Use of laws and design rules, standards and specifications
- Worked examples of construction and design

3.10 Design of aluminium alloys structures

- Comparison of design between steel and aluminium structures
- Lightweight structures
- Standard alloys for practical use and relevant stresses and strains
- Effects of heat affected zone (HAZ) (softening)
- Special design regarding profiles
- Significance of defects
- Range of application (vehicles, rolling stocks, ships, aircraft, vessels and space)
- Use of standards and specifications
- Worked examples

3.11 Reinforcing-steel welded joints

- Reinforcing-steel types, properties
- Direct and indirect loading
- Types of joints used (lap, cruciform)
- Calculation
- Weldability with respect to weld joint strength
- Preheating in respect to bar diameter
- Application of welding processes
- Standards and specifications (ISO 17660 series and National Standards)

3.12 Introduction to fracture mechanics

- Viewpoint of fracture mechanics
- Application of fracture mechanics
- Linear elastic fracture mechanics
- Fundamentals of elastic-plastic fracture mechanics
- Critical flaw size, KIc-value
- Fracture mechanics testing (CTOD, etc.)
- Sub-critical crack growth
- Fatigue testing
- Standards

Module 4: Fabrication, applications engineering

4.1 Introduction to quality assurance in welded fabrication

- Concept of quality assurance and quality control (including analysis, continuous improvement)
- Weldability
- Quality manual

- Quality plan
- Audit of plant
- Personnel and equipment
- Maintenance
- Inspection
- Activities of the welding engineer/technologist/specialist/practitioner in the different functions in industry
- Standards (QMS guidebook, ISO 9000 series, ISO 3834, national and international standards)

4.2 Quality control during manufacture

- Documentation to national, regional and international standards, e.g WPS
- Advantages to the quality of welded constructions
- Welding sequence
- Welding coordination and inspection personnel; qualification tasks and responsibilities (ISO 14731, ISO 9712, and National standards)
- Procedure qualification (as described in ISO 15607) and National standards
- Welding procedure specification (WPS) - how to create and develop
- Welder qualification (ISO 9606 series, EN 287-1, and National standards)
- Welding operator qualification (EN 1418, ISO and National standards)
- Traceability (materials identification, welder/operator, procedures, certificates)
- Possible methods of monitoring, control and storage of fabrication data
- Calibration and validation of measuring equipment
- **Practical exercises:**
  - Welding procedure qualification
  - Welder and welder operator qualification

4.3 Residual Stresses and Distortion

- Influencing factors
- Thermal data of the materials
- Origin of the residual stresses and deformation
- Magnitude of longitudinal and transverse shrinkage stresses
- Relationship between heat input, shrinkage stresses and distortion
- Methods of residual stress measurement
- Welding sequence techniques
- Effects of residual stresses on the behaviour of the structure in service
- Methods of reducing residual stresses or distortion
- Correction and removal of welding deformation (pressing, rolling, local heating, etc.)
- Examples of control of distortion

4.4 Plant facilities, welding jigs and fixtures

- Layout of production line
- Jigs, fixtures and positioners (types, applications, advantages, special precautions)
- Roller beads, manipulators
- Cables, electrical connections, and special precaution
- Operational environment

- Auxiliary equipment (for fit up, movement, backing gas devices, flow meters, etc)
- Fume extraction (type of equipment, air flow)
- Joint fit up
- Tack welding and their removal
- Storage, distribution and handling of consumables (gases and filler material, baking and drying furnace)
- Equipment for preheat, postheat, and other heat treatments, also temperature control including furnace and local heat treatment
- Maintenance

4.5 Health and Safety

- Introduction to health and safety requirements
- Survey of safety and environmental aspects, risk assessment
- Hazards of electric power
- Electro-magnetic fields
- Connecting of equipment
- Problems with shielding gases
- Radiation and eye protection
- Welding fume emission
- Exposure limits MAC and OEL values
- Ventilation and fume extraction
- Ergonomics
- Determination of acceptable emissions
- Tests for measuring emissions
- Noise levels and ear protection
- Special risks for automated processes
- Standards and regulations

4.6 Measurement, Control and Recording in Welding

- Methods of measurement (electrical parameters, gas flow rate, temperature, velocity)
- Instruments (types, measuring applications)
- Temperatures (ISO 13916), humidity, wind
- Cooling time e.g. t 8/5
- Welding parameters (voltage, current, speed, gas flow rate, etc.)
- Control in heat treatment (heating and cooling rate, CR ISO 17663)
- Calibration and validation of equipment (ISO 17662)
- Laboratory exercises
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4.7 Non Destructive Testing

- Types of weld imperfections (IIW-designations classification according to ISO standards)
- Acceptance criteria (e.g. ISO 5817, ISO10042, and EN 12062)
- Fundamentals of NDT methods (visual, dye penetrant, magnetic particle, eddy current, acoustic emission, radiography, ultrasonic, etc.)
- Field of application and limitations
- Design in respect of NDT
- Calibration

- Interpretation (IIW Radiographic reference)
- Recording of data
- Correct selection of the NDT methods versus application (e.g. CEN/TR 15135)
- Qualification and certification of NDT personnel
- NDT procedures
- Automation of NDT (computer aid evaluation, etc.)
- Use of standards and specifications
- Health and safety aspects
- Laboratory exercises

4.8 Economics

- Analysis of welding costs
- Deposition rate
- Costs of labour
- Costs of welding consumables
- Costs of equipment
- Return on investment.of energy
- Welders duty cycle
- Calculation of welding costs
- Cost awareness (of labour, consumables, equipment, gases, energy, etc.)
- The application of software, calculation programmes
- Measures for decreasing welding costs
- Mechanisation
- Automation
- Robotics

4.9 Repair Welding

- Welding repair procedure specification
- Welding repair plan
- Welding repair procedure qualification
- NDT of the weld repair
- Special precautions

4.10 Fitness for Purpose

- Introduction to IIW SST 1093-8 and ISO/TR 15235
- Significance of defects
- Engineering critical assessment techniques

4.11 Case Studies

- Steel and lightweight structures, boilers and pressure vessels, chemical plants and pipelines, shipbuilding and offshore applications, transportation (automobiles, railways), aerospace applications
- Common items to be covered:
- Standards and specifications, design,
- Choice of materials, welding processes,
- Site welding (transport and final assembly),

- Consumables, welding procedures,
- Tolerances on weld preparation and fit-up,
- Post