DI04019041: Fabrication Technology - Unit 3

GTU Course Presentation

July 24, 2026

Course Contents I

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Course Contents II

Overview of Welding Process Requirements I

Introduction to Welding Process Requirements

Overview of Welding Process Requirements II

Key Points

- Joint Fit-up and Alignment: Specifications for root opening, root face, and groove angle per AWS D1.1 to control penetration and minimize distortion.
- Metallurgical Compatibility: Selection of filler metal and shielding gas based on base metal composition (e.g., carbon steel, stainless steel, aluminum).
- Preheating and Interpass Control: Essential for carbon equivalent (CE) > 0.40 to prevent hydrogen-induced cracking (HIC) and manage heat-affected zone (HAZ) hardness.
- Post-Weld Heat Treatment (PWHT): Required for stress relieving, tempering martensite, and maintaining fracture toughness in heavy-section steel welds.

Arc Welding Parameters: Current and Voltage I

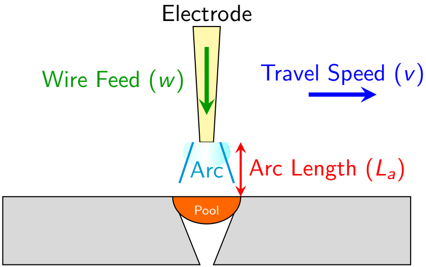
Electrical parameters setting (Voltage, Current)

Arc Welding Parameters: Current and Voltage II

Key Points

- Welding Current (Amperage): Directly governs penetration depth and electrode melting rate. Direct relationship: Current (I) controls energy density.
- Arc Voltage: Controls the arc length and width of the weld deposit. Higher voltage increases bead width, flattens the reinforcement, and increases risk of undercuts.
- Polarity (DC polarity types): DCEP (Reverse Polarity) deposits heat on the electrode (typically 70% for GMAW/SMAW) yielding deeper penetration. DCEN (Straight Polarity) yields higher deposition rate but shallower penetration.
- Heat Input Formula: Calculated as H = $(\eta * V * I * 60)/(v * 1000) in kJ/mm, where \eta is thermal efficiency and v is travel speed in m$

Arc Welding Parameters: Speed, Feed, and Arc Length I



Arc Welding Parameters: Speed, Feed, and Arc Length II

Key Points

- Welding Speed: Excessive travel speed limits heat input, causing lack of fusion, undercut, and rapid cooling. Low speed increases weld pool size, risk of burn-through, and coarse grain structure.
- Wire Feed Rate: In GMAW/FCAW, wire feed speed (WFS) controls the deposition rate and is directly proportional to welding current. Proper balance prevents stubbing or burn-back.
- Arc Length: The distance from electrode tip to weld pool. Must be held stable (typically 1.5 to 3.0 mm depending on electrode diameter). Long arc increases voltage, reduces shielding efficacy, and creates spatter.

Gas Welding Parameters: Gas Pressure Settings I

Gas pressure regulation and safety settings

Gas Welding Parameters: Gas Pressure Settings II

Key Points

- Fuel and Oxidizer: Acetylene (C_2H_2) provides the highest combustion temperature (3100 C); Oxygen (O_2) supports combustion and regulates heat density.
- Acetylene Pressure Limit: Critical safety rule: Acetylene working pressure must never exceed 15 psi (1.03 bar) as it undergoes explosive decomposition above this limit.
- Dual-Stage Regulators: Installed on cylinders to step down high storage pressures (2200 psi for Oxygen, 250 psi for Acetylene) to low, constant working pressures (1 to 15 psi).
- Safety Components: Flashback arrestors are mandatory to prevent retrogressive propagation of flame back into the hoses and regulators.

Gas Welding Parameters: Gas Flow Rates and Flame Types I

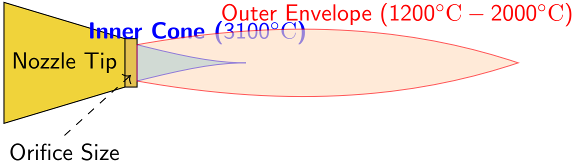
Gas flow rate settings and flame chemistry

Gas Welding Parameters: Gas Flow Rates and Flame Types II

Key Points

- Neutral Flame: Equal volumetric flow rates (1:1 ratio). Features a well-defined inner cone and blue envelope. Used for carbon steels, cast iron, and copper.
- Carburizing (Reducing) Flame: Higher flow rate of Acetylene (Oxygen/Acetylene < 1.0). Features an intermediate 'acetylene feather'. Used for high-carbon steels, alloy steels, and hardfacing.
- Oxidizing Flame: Excess Oxygen flow rate (Oxygen/Acetylene $= 1.1$ to 1.5). Features a short, pointed inner cone. Used for welding brass and bronze (to form a protective ZnO layer).
- Volumetric Flow Control: Flow rates (measured in CFH or L/h) are regulated using needle valves on the

Gas Welding: Nozzle Types and Optimization I



Gas Welding: Nozzle Types and Optimization II

Key Points

- Nozzle Selection (Orifice Size): Tips are designated by numbers (e.g., #1 to #10) or diameter. Higher numbers correspond to larger orifices and higher flow capacities.
- Optimized Nozzle Number: Chosen based on base metal thickness (e.g., Nozzle #2 for 1.6 mm sheet, #5 for 5.0 mm plate) to supply correct heat input rate without melting too wide an area.
- Flame Velocity Balance: The exit velocity of gas must match the combustion velocity of the mixture. Excess velocity blows the flame off; deficient velocity causes backfire.
- Nozzle Maintenance: Cleaning tip orifices with wire tip cleaners prevents carbon build-up and ensures laminar gas flow, preventing turbulent, erratic flames.

Welding Process Requirements: Standards and Verification I

Industrial compliance and qualification standards

Welding Process Requirements: Standards and Verification II

Key Points

- Welding Procedure Specification (WPS): Standard document listing all essential variables (Voltage, Current, Gas flow, Speed) required for a specific joint qualification.
- Procedure Qualification Record (PQR): Record of test results (tensile strength, bend tests, hardness) validating that the WPS produces sound weld joints.
- Welder Qualification Test (WQT): Evaluates a welder's ability to maintain parameters (arc length, speed, angle) within tolerances specified by ASME Section IX or AWS D1.1.
- Process Feedback Loops: Modern automated systems use closed-loop controls to dynamically adjust voltage,

Metallurgy and Objectives of Preheating I

Preheating slows the cooling rate of the weld metal and heat-affected zone (HAZ), promoting hydrogen diffusion and preventing martensite formation.

Metallurgy and Objectives of Preheating II

Key Points

- Slowing the cooling rate allows the steel to avoid forming brittle martensitic microstructures in the HAZ, favoring tougher pearlite or bainite.
- Provides thermal energy that assists diffusible hydrogen to escape from the weldment, directly preventing hydrogen-induced cracking (HIC).
- Reduces the temperature gradient between the weld zone and base metal, which lowers thermal contraction stresses and residual stress levels.
- Compensates for the rapid heat sink effect in heavy sections (plates over 25mm), ensuring consistent penetration and weld bead fusion.

Determining Preheat Temperature (Carbon Equivalent & Thickness) I

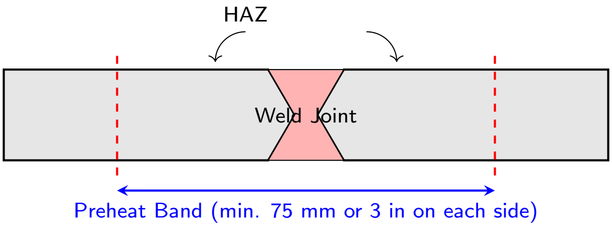
The necessity and minimum temperature of preheating are calculated based on the chemical composition (CE) of the steel and the joint thickness.

Determining Preheat Temperature (Carbon Equivalent & Thickness) II

Key Points

- Carbon Equivalent (CE) formula dictates weldability: $CE = C + Mn/6 + (Cr+Mo+V)/5 + (Ni+Cu)/15$. Higher CE values require higher preheat.
- Under AWS D1.1, steels with CE $<=$ 0.40 rarely need preheat, while CE $>$ 0.45 requires strict thermal controls ranging from 100°C to 200°C.
- Governed by thickness limits: Thick plates act as massive heat sinks, accelerating cooling rates and necessitating preheat even for low CE steels.
- Welding process hydrogen rating (e.g., H4, H8, H16) scales the minimum preheat; lower hydrogen electrodes allow lower preheat temperatures.

Preheat Zone and Joint Layout I



Preheat Zone and Joint Layout II

Key Points

- The preheat band must extend at least 75 mm (3 inches) in all directions from the center of the weld joint.
- Base metal must be heated uniformly through the entire thickness within the designated preheat band prior to starting the weld.
- Temperature monitoring must be performed at a distance equal to the thickness of the plate (but not less than 75 mm) from the weld prep.
- Improper preheating zones result in localized thermal gradients, defeating the purpose of preheating and initiating cracking.

Interpass Temperature Control during Welding I

Interpass temperature refers to the temperature of the weldment in the joint area immediately prior to the start of the next pass.

Interpass Temperature Control during Welding II

Key Points

- Minimum interpass temperature is typically equal to the minimum preheat temperature to maintain metallurgical benefits throughout the weld.
- Maximum interpass temperature must be restricted to prevent excessive grain growth in the HAZ, which reduces yield strength and toughness.
- For austenitic stainless steels, maximum interpass is kept below 150°C (300°F) to avoid chromium carbide precipitation (sensitization) and hot cracking.
- For high-strength low-alloy (HSLA) steels, a high interpass temperature degrades the quenching effect, leading to coarse grain structures.

Post-Heating for Hydrogen De-embrittlement I

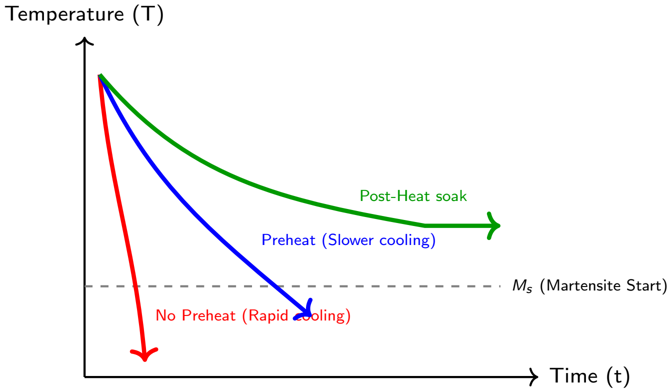
Post-heating involves maintaining or raising the temperature of the weld joint immediately after welding to facilitate hydrogen diffusion.

Post-Heating for Hydrogen De-embrittlement II

Key Points

- Conducted immediately after welding, usually at 200°C to 300°C (400°F to 570°F), before the joint cools below the preheat temperature.
- Specifically targets hydrogen diffusion; it speeds up the migration of trapped atomic hydrogen out of the weld and heat-affected zone.
- Crucial for thick-section welds in high-strength steels, highly constrained joints, or when high-hydrogen welding processes are used.
- Typically held for a minimum of 2 to 4 hours depending on material thickness, significantly reducing the risk of delayed cold cracking.

Heat Treatment Comparison & Cooling Rate Diagram I



Heat Treatment Comparison & Cooling Rate Diagram II

Key Points

- The diagram demonstrates how preheating flattens the cooling curve, keeping the heat-affected zone above the critical cooling rate.
- Avoiding the rapid descent into the martensitic region (M_s) prevents the formation of hard, brittle microstructures.
- Post-heating maintains the temperature above ambient levels, providing the thermal activation energy needed for hydrogen diffusion.
- A controlled thermal cycle is the primary defense against hydrogen-induced cold cracking and excessive weld residual stresses.

Post-Weld Heat Treatment (PWHT) and Design Codes I

Post-Weld Heat Treatment (PWHT) is a sub-critical annealing process designed to relieve residual stresses and improve mechanical properties.

Post-Weld Heat Treatment (PWHT) and Design Codes II

Key Points

- Differs from post-heating: PWHT uses higher temperatures (550°C - 650°C for carbon steels) to relieve weld shrinkage stresses.
- ASME Section VIII Div 1 (UCS-56) defines holding temperatures and soaking times based on alloy composition and nominal thickness.
- Restores ductility, reduces weldment hardness (especially in the HAZ), and significantly improves resistance to stress corrosion cracking.
- In industrial fabrication, failure to properly execute PWHT in thick-walled pressure vessels can lead to catastrophic brittle fracture in service.

Introduction to Preheating & Interpass Temperature I

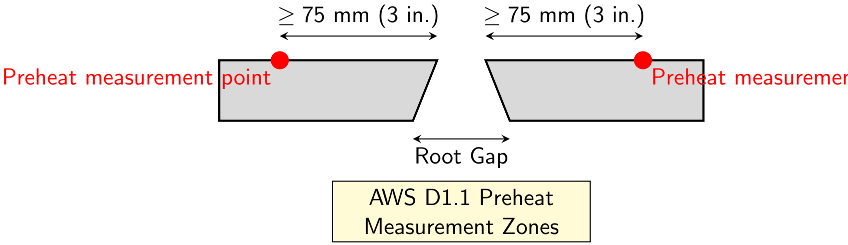
Preheating is the heating of the base metal to a specified minimum temperature prior to welding. Interpass temperature is the temperature of the weldment between successive weld passes.

Introduction to Preheating & Interpass Temperature II

Key Points

- Primary goal: Slow down the cooling rate in the Weld Metal and Heat-Affected Zone (HAZ) to allow hydrogen diffusion, preventing Hydrogen-Induced Cracking (HIC).
- Reduces shrinkage stresses and minimizes the formation of hard, brittle martensite phases in the HAZ.
- Mandated by standards like AWS D1.1 and ASME Section VIII based on Material Composition (Carbon Equivalent) and Joint Thickness.
- Maximum interpass temperature must be monitored to control grain growth, carbide precipitation, and sensitization in alloyed steels.

Preheat Measurement Zone (AWS D1.1) I



Preheat Measurement Zone (AWS D1.1) II

Key Points

- AWS D1.1 specifies measuring preheat temperature at least 75 mm (3 in.) away from the weld joint in all directions.
- Temperature must be verified on the side opposite to heating (if heating is localized on one side) to ensure through-thickness heating.
- Applying preheat thermal sticks too close to the weld pool may contaminate the weld with carbon/sulfur residues.

Temperature Sticks (Tempilstiks): Working Principle I

Temperature indicating crayons, commonly known as Tempilstiks, are designed with materials of sharp, defined melting points to verify preheat, interpass, and post-heat temperatures.

Temperature Sticks (Tempilstiks): Working Principle II

Key Points

- Melting Point Accuracy: Engineered to melt within +/- 1% tolerance of their rated temperature (available from 38°C to over 1000°C).
- Dry Stroke Technique: The crayon is stroked onto the heated metal surface. If the chalk-like mark melts immediately, the metal has reached or exceeded the rated temperature.
- Wet Stroke Technique: A mark is applied to the cold surface before heating. The operator monitors the mark during heating; it turns into a shiny, liquid smear as soon as the rated temperature is reached.
- Industrial Limitations: Non-recording method; requires manual inspector logging. Special low-halogen,

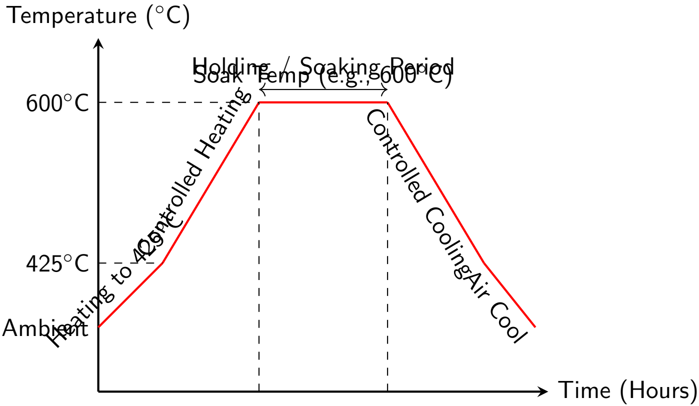
Post-Weld Heat Treatment (PWHT) Fundamentals I

PWHT is a controlled heating and cooling process applied to a completed weldment. It is primarily used to relieve residual stresses and improve material toughness.

Key Points

- Thermal Stress Relief: Relieves high tensile residual stresses induced by welding solidification. Elevated temperature reduces yield strength, causing local plastic deformation (creep) that relaxes stress.
- Hardness Reduction: Tempers hardened martensitic microstructures in the heat-affected zone (HAZ), reducing vulnerability to hydrogen cracking and Stress Corrosion Cracking (SCC).
- Dimensional Stability: Minimizes risk of geometric distortion during subsequent machining or during the component's operational life.
- ASME Section VIII Div 1: Mandates PWHT for carbon steels above specific thickness thresholds (typically 38 mm or 1.5 in.) to ensure crack resistance.

PWHT Thermal Cycle Profile I



PWHT Thermal Cycle Profile II

Key Points

- ASME rules require controlled heating and cooling rates above 425°C to prevent thermal stress gradients across thick sections.
- Soaking / Holding temperature is held at a specific range (e.g., 590-620°C for carbon steel) to facilitate stress relaxation without altering mechanical properties.
- Soaking time is determined by material thickness, typically 1 hour per 25 mm (1 inch) of material thickness.

3.2 Fabrication Procedures & Sequence of Thermal Operations I

A structured fabrication procedure coordinates welding and thermal activities sequentially to maintain metallurgy and compliance with the Welding Procedure Specification (WPS).

3.2 Fabrication Procedures & Sequence of Thermal Operations II

Key Points

- Fit-up and Joint Preparation: Check bevel angles, root opening, and clean the joint edges of grease, moisture, rust, and oil.
- Preheating Stage: Heat the joint using gas burners or electrical induction pads. Measure with thermal sticks at 75 mm from the weld line to ensure the temperature is at or above the minimum preheat requirement.
- Deposition of Weld Passes: Initiate the root pass and subsequent fill passes. Before starting each pass, verify the interpass temperature using interpass thermal sticks to ensure it is below the maximum limit.
- Hydrogen Bake-out / Post-heating: Immediately after welding, heat to 200-300°C for 2-4 hours to accelerate hydrogen effusion and prevent cold cracking prior to

Quality Control, Code Compliance & Documentation I

Strict quality control ensures that thermal boundaries are respected and documented, which is a requirement for final structural acceptance.

Quality Control, Code Compliance & Documentation II

Key Points

- Welding Procedure Specification (WPS): Specifies the preheat, interpass, and post-heat requirements. Fabricators must weld within these qualified parameters.
- Procedure Qualification Record (PQR): Documents the actual thermal cycles and testing results used to qualify the WPS.
- Documentation of Thermal Sticks: Inspectors must record melting observations on the weld inspection report, noting crayon ratings and actual passes.
- Continuous Monitoring: For critical components (e.g., pressure vessels, offshore jackets), tempil sticks serve as a verification check, while thermocouples provide continuous chart-recorded records.

Plate Edge Bending for Rolling (Pre-bending) I

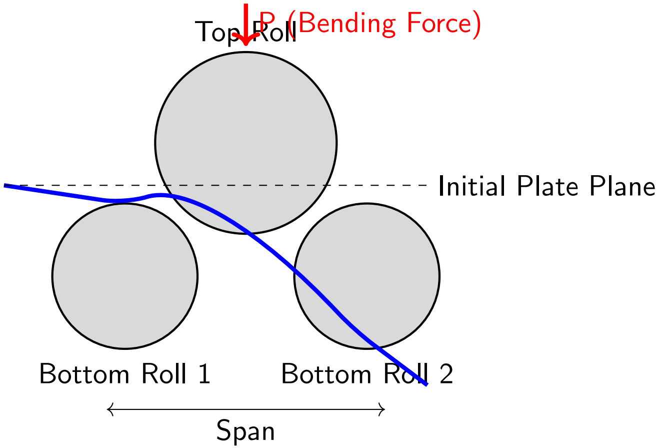
The Engineering Necessity of Edge Pre-bending or Crimping

Plate Edge Bending for Rolling (Pre-bending) II

Key Points

- During standard plate rolling, the zone near the plate edges cannot be deformed by the rolls because it remains outside the bending span between the contact points of the rolls.
- This leaves straight, unbent flat zones at both ends of the rolled shell, typically extending 1.5 to 2.5 times the plate thickness.
- Pre-bending (crimping) is performed prior to the main rolling operation to pre-curve the edges of the plate to the exact target shell radius.
- Without pre-bending, the shell will exhibit a 'peak' or flat spot at the longitudinal weld seam, violating ASME Sec VIII Div 1 roundness tolerances and introducing high local stress concentrations.

Mechanics of Plate Pre-bending I



Mechanics of Plate Pre-bending II

Key Points

- The top roll acts as the punch applying load P, while the two bottom rolls act as the die supports.
- The plate is fed into the machine, and its edge is positioned precisely under the top roll to receive the initial bending moment.
- Pre-bending is typically performed using heavy-duty press brakes with radius tooling or directly inside initial pinch or 4-roll bending machines.
- The profile of the pre-bent edge is verified using a curved template matching the nominal inside or outside radius of the cylinder.

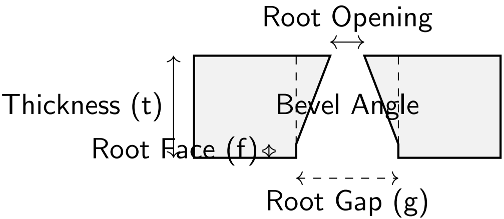
Comparison of Rolling Machines and Deformational Physics

Plate Rolling Technology and Machinery II

Key Points

- Pyramidal 3-Roll Machines: The top roll moves vertically, and bottom rolls rotate at fixed centers. They cannot pre-bend effectively and require flipping the plate.
- Initial Pinch 3-Roll Machines: Features one top roll, one pinching bottom roll directly below, and an adjustable side roll that performs the bending. Good for pre-bending.
- 4-Roll Double Pinch Machines: The top and bottom rolls clamp the plate, while two lateral side rolls perform bending. This allows complete pre-bending of both edges in a single setup.
- Hot Rolling vs. Cold Rolling: Cold rolling is standard for carbon steel up to 50mm (dependent on machine capacity); hot rolling (above recrystallization temp.

Weld Edge Preparation (Groove Geometry) I



Weld Edge Preparation (Groove Geometry) II

Key Points

- Edge preparation is critical to ensure complete joint penetration (CJP) and minimize welding defects like lack of fusion and slag inclusion.
- Single-V grooves are used for plates up to 20mm; double-V grooves are used for thicker plates to balance angular distortion and minimize weld metal volume.
- Key dimensions include the Root Face (prevents burn-through), Root Gap (allows root pass penetration), and Bevel Angle (typically 30 to 37.5 degrees).
- Common industrial methods for preparation are flame cutting (oxy-fuel), plasma arc cutting, and mechanical edge milling/planing.

Weld Edge Selection & Standard Compliance I

Designing Weld Joints to ASME Section VIII and IX Standards

Weld Edge Selection & Standard Compliance II

Key Points

- ASME Section VIII Div 1 UW-35 enforces rules for weld reinforcement limits, ensuring that the weld profile is smooth and gradual to reduce stress concentration.
- Preparation selection criteria: Plate thickness, access constraints (inside vs. outside welding), welding process (SMAW, SAW, FCAW, or GTAW), and joint classification.
- Planing and milling are preferred over thermal cutting for alloy steels and stainless steels to prevent thermal degradation and keep the heat-affected zone (HAZ) minimal.
- Back-gouging of the root pass on the second side of double-welded joints is mandatory under ASME rules to ensure sound weld metal before deposition of the second-side root.

Plate Marking for Shells and Dish-Ends I

Precision Layout Procedures and Dimensional Correction Factors

Plate Marking for Shells and Dish-Ends II

Key Points

- Shell Development Length: Calculated on the mean diameter of the shell. L = pi * (ID + t) or L = pi * (OD - t) to account for neutral axis deformation during bending.
- Diagonal Checking: The marked plate layout must be verified for squareness by measuring the diagonals (which must be equal, within +/- 1mm per meter) to prevent spiraling of the cylinder during rolling.
- Dish-End Blank Diameter: Formulated based on crown radius (R), knuckle radius (r), straight flange height (SF), and nominal thickness (t) to ensure correct finished dimensions.
- ASME F&D (Flanged and Dished) blank diameter calculations typically use the empirical formula: Blank Diameter = 1.09 * OD + 2 * SF + thinning allowance.

Layout Patterns, Nozzle Openings, and Material Traceability

Marking for Tube Sheets and Reinforcing (RF) Pads II

Key Points

- Tube Sheets: Requires coordinate marking (X-Y layout) for drilling tube holes. Pitch patterns can be triangular (30 or 60 degrees) or square (45 or 90 degrees) according to TEMA standards.
- Reinforcing (RF) Pads: Laid out around nozzle openings on the shell or head. Must include a tell-tale weep hole (1/4 inch NPT) to detect weld leaks and vent gases during welding.
- Orientation Marks: Permanent punch marks indicating the vessel centerlines (0°, 90°, 180°, 270°) must be maintained throughout fabrication for alignment of nozzles, brackets, and internals.
- Material Traceability: Heat numbers and material

Oxy-Fuel Gas Cutting (OFC) Principles I

Oxy-fuel cutting relies on the chemical reaction of high-purity oxygen with the base metal (carbon steel) at elevated temperatures. The metal is preheated to its kindling temperature (approx. 900°C for mild steel) using an fuel gas (acetylene, propane, or natural gas) and oxygen mixture. A high-velocity stream of pure oxygen is then directed at the heated area, rapidly oxidizing (burning) the iron and blowing away the molten slag (FeO, Fe2O3, Fe3O4) to form the kerf.

Oxy-Fuel Gas Cutting (OFC) Principles II

Key Points

- Applicability: Limited to metals whose oxides have a lower melting point than the base metal itself (primarily carbon steels and low-alloy steels). Stainless steels and aluminum cannot be cut efficiently due to refractory oxide layers (Cr_2O_3, Al_2O_3).
- Preheating Flame: Primary flame melts/heats the surface, while the central high-purity (minimum 99.5%) oxygen jet initiates and sustains the exothermic oxidation reaction.
- Drag Line Analysis: Drag lines indicate cutting speed and oxygen pressure. Correct cutting speed produces nearly vertical drag lines, whereas excessive speed leads to curved drag lines and incomplete penetration.
- Kerf Width: Typically ranges from 1.5 mm to 3.0 mm depending on plate thickness, nozzle size, and cutting

Plasma Arc Cutting (PAC) Technology I

Plasma Arc Cutting (PAC) uses a constricted, high-velocity jet of ionized gas (plasma) to conduct electricity from the torch nozzle to the workpiece. The intense heat of the arc (up to 20,000°C or 30,000 K) melts the metal, and the high-velocity gas jet physically blows the molten metal out of the cut. PAC can cut any electrically conductive material, making it ideal for stainless steels, aluminum, and copper alloys that cannot be cut by oxy-fuel.

Plasma Arc Cutting (PAC) Technology II

Key Points

- Plasma Gases: Choice of gas depends on material. Air or Oxygen is used for carbon steel; Nitrogen or Argon-Hydrogen mixtures (H35) are preferred for stainless steel and aluminum to prevent oxidation.
- Dual Gas Technology: Utilizes a primary plasma gas to form the arc and a secondary shield gas (e.g., water, air, or nitrogen) to cool the torch and constrict the plasma jet, improving cut quality and nozzle life.
- Heat Affected Zone (HAZ): Significantly narrower than oxy-fuel cutting due to higher energy density and travel speeds, reducing thermal distortion of thin plates.
- Kerf Angle (Bevel): Plasma cuts typically exhibit a slight bevel (1° to 3° on the 'good' side of the cut) due to the shape of the plasma jet.

Process Comparison and Code Guidelines I

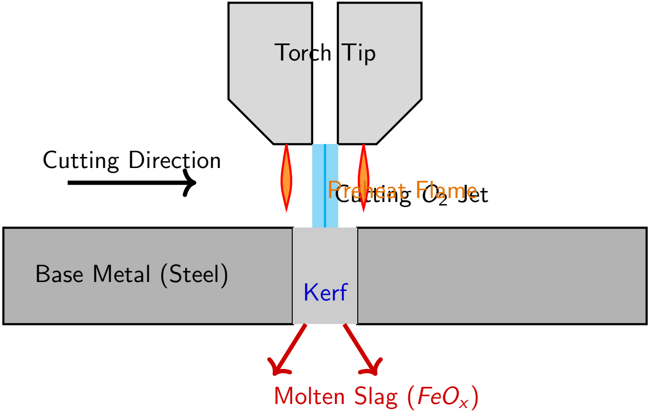
Selecting between Oxy-Fuel and Plasma cutting requires analyzing material composition, thickness, production rate, and code compliance. ASME Section VIII Div 1 (pressure vessels) and AWS D1.1 (structural welding) govern the preparation of material edges. Thermal cutting processes must produce edges free of cracks, excessive roughness, and slag to ensure weld integrity.

Process Comparison and Code Guidelines II

Key Points

- Thickness Limits: Oxy-fuel is highly economical for thick plates (above 50 mm up to 300 mm+). Plasma is superior for thin to medium plates (under 50 mm) where speed and low distortion are critical.
- Edge Preparation: Both processes can be automated with multi-torch beveling heads to cut single-V, double-V, or K-bevel prep profiles in a single pass.
- ASME Sec VIII Div 1 UW-31 & UW-35: Requirements for edge preparation. Slag and oxidation from cutting must be removed by grinding to sound metal before welding, particularly on stainless steels cut with plasma/air.
- Hardness Increase: Thermal cutting can induce localized hardening (martensite formation) on the cut edges of high-carbon or low-alloy steels. Preheating or

Oxy-Fuel Cutting Mechanism Diagram I



Oxy-Fuel Cutting Mechanism Diagram II

Key Points

- The torch tip focuses outer preheating flames to raise the steel temperature to its ignition point (900°C).
- A central, high-velocity oxygen jet oxidizes the iron exothermically and expels the liquid oxide slag downward.
- The width of the removed material is the 'kerf', which must be accounted for in fabrication templates (typically 2-3 mm offset).
- Drag lines (not pictured) form on the cut surface as the torch moves; their angle indicates cutting speed adequacy.

Shell Alignment Methods I

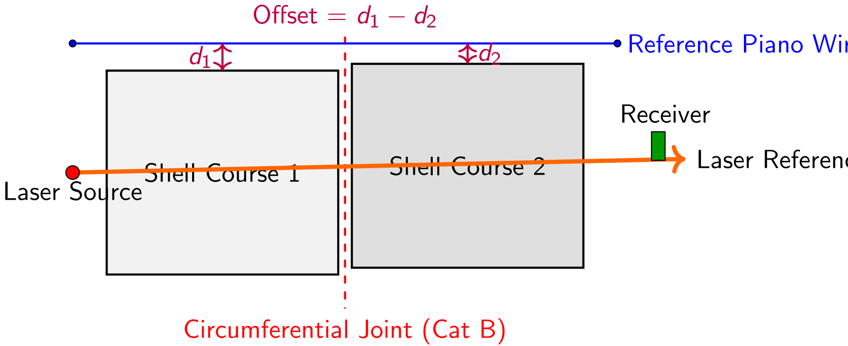
Shell alignment is a critical step in pressure vessel fabrication (under codes like ASME Sec VIII Div 1 UW-33, which specifies maximum offset tolerances for longitudinal and circumferential joints). Misalignment (offset) causes high localized stress concentrations during operation. Traditional physical string/piano wire methods are being supplemented or replaced by high-precision optical laser alignment systems.

Shell Alignment Methods II

Key Points

- String / Wire Method: A high-tensile steel piano wire is stretched tightly parallel to the shell axis. Optical micrometers or calipers measure the radial distance from the wire to the shell wall at multiple points along the length to identify sag, peaking, or misalignment.
- Laser Alignment: Emits a highly collimated laser beam along the central longitudinal axis of the shell sections. Photo-diode receivers or target plates measure horizontal and vertical deviations with sub-millimeter precision (<0.1 mm).
- ASME Sec VIII Div 1 UW-33 Alignment Tolerances: For longitudinal joints in category A welds, the maximum offset depends on thickness (e.g., for plates over 50 mm, tolerance is the lesser of 1/16t or 3/8 inch / 10 mm).
- Correction Techniques: Hydraulic jacks, alignment dogs,

Shell Alignment Diagram (Wire vs. Laser) I



Shell Alignment Diagram (Wire vs. Laser) II

Key Points

- The blue reference line represents a piano wire stretched tautly, measuring external radial distance variation (d_1 and d_2).
- The red/yellow line illustrates an internal laser alignment beam passing through the geometric centers, showing any vertical/horizontal shell course drift.
- A physical gap and step at the circumferential joint (Category B) represents the fit-up misalignment to be corrected.
- Internal spiders and external alignment dogs are manipulated until the offset ($d_1 - d_2$) falls within the allowable limits.

Nozzle Orientation Marking I

Nozzle orientation marking is the process of locating nozzle positions on a shell course. Marking must be incredibly precise to ensure piping fit-up aligns with plant design layout. The process involves identifying the Shell Reference Lines (usually 0°, 90°, 180°, and 270° orientation lines), calculating the circumferential length (arc length) from the nearest reference line, and laying out the nozzle centerlines.

Nozzle Orientation Marking II

Key Points

- Reference Lines: The shell's circumferential length is calculated using
  the actual measured Outer Diameter (OD) as $C = \pi \times OD$. $Thecircumferenceisthendividedintofourquadrants (0, 90, 18$
- Arc Length Calculation: The location of a nozzle at angle θ $isdeterminedbycalculatingthearclengthfromaprimaryreferenc$
  $(\theta/360) \times C$. $Thisdistanceismeasuredalongtheshellcircumferencewithaflex$
- Longitudinal Layout: The longitudinal nozzle center position is marked relative to the circumferential weld seam (datum line) as specified in the vessel drawings.

Reference Line Marking by Dumpy Level I

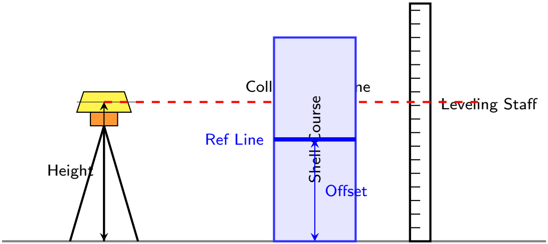
Precision leveling and baseline establishment for multi-course shell assembly.

Reference Line Marking by Dumpy Level II

Key Points

- A Dumpy Level is used to establish a true horizontal reference plane across the shell circumference.
- Required during vertical assembly or assembly on rotators to prevent progressive tilt or banana effect.
- Setup involves centering the instrument and leveling the tribrach using the circular bubble vial.
- A Master Benchmark (MBM) is transferred from the civil foundation to the shell surface.
- Circumferential points are marked at regular intervals (e.g., every 45 degrees) using a steel rule or optical target.

Dumpy Level Survey Setup I



Dumpy Level Survey Setup II

Key Points

- The horizontal line of sight (plane of collimation) serves as a virtual datum plane.
- Leveling staff readings are taken at key circumferential coordinates to check height variations.
- Ensures the top edge of each shell course is parallel to the datum plane within 1.5 mm tolerance.
- Critical for preventing cumulative angular deviation in tall columns (such as distillation towers).

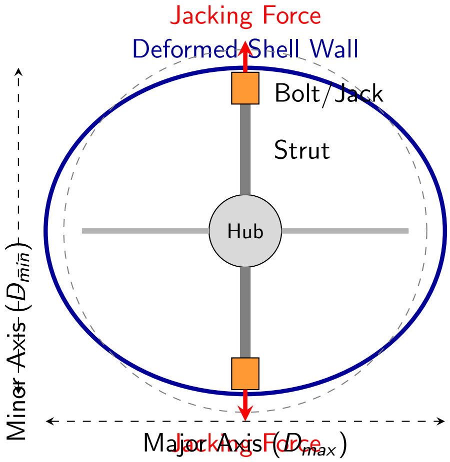
Geometric deviation (out-of-roundness) in rolled plates under ASME code tolerances.

Ovality Measurement of Cylindrical Shells II

Key Points

- Ovality is measured as the difference between maximum and minimum internal diameters (D_max - D_min) at a given cross-section.
- ASME Section VIII, Div. 1, UG-80 rules: Shell out-of-roundness must not exceed 1% of the nominal inner diameter.
- For shells subjected to external pressure, stricter limits apply under UG-80(b) based on L/D and D/t ratios.
- Measured using telescopic inside micrometers, laser trackers, or chord-based checking devices.
- Main sources of ovality: non-uniform plate rolling, gravity-induced sagging, and weld shrinkage of longitudinal seams.

Ovality Rectification using Internal Spiders I



Ovality Rectification using Internal Spiders II

Key Points

- Internal spider assemblies use radial struts (pipe/structural sections) radiating from a central hub.
- Jacking force is applied along the minor axis to push the flattened shell wall outwards.
- Ensure backing plates (pads) are welded to the strut ends to prevent local stress concentration or shell punctures.
- Spiders are kept in position until circumferential joints are fully welded to lock the circular geometry.

Profile Checking by Template (Peaking) I

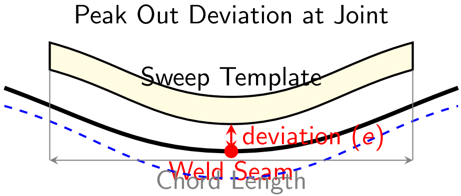
Local geometric deviations at longitudinal and circumferential weld seams (Peak In / Peak Out).

Profile Checking by Template (Peaking) II

Key Points

- Peaking refers to localized flat spots (Peak In) or ridges (Peak Out) forming at weld joints due to weld shrinkage.
- ASME UG-80 requires checking local deviations using a sweep template cut to the nominal radius of the shell.
- The sweep template must span a chord length equal to 20% of the inside diameter (minimum 300 mm, maximum 1000 mm).
- Feeler gauges are inserted between the shell plate and the template to measure the gap (deviation 'e').
- Peaking increases local bending stress under pressure, leading to high stress concentration factors (SCF) and fatigue risk.

Peak Out Deviation checking using Sweep Template I



Peak Out Deviation checking using Sweep Template II

Key Points

- The template chord length is determined based on shell diameter to ensure accurate localized assessment.
- For longitudinal seams, the template is held perpendicular to the weld axis; for circumferential seams, parallel.
- Corrective action: mechanical re-pressing, flame heating with thermal cooling cycles, or localized wedge dogs.
- All profile deviations must be documented in the inspection release note prior to hydrotesting.

Fabrication Quality Control Summary I

Summary of key dimensional controls for pressure vessel shell fabrication.

Fabrication Quality Control Summary II

Key Points

- Leveling controls: Dumpy level survey establishes the primary circumferential datum lines to prevent axial alignment errors.
- Ovality controls: Internal spiders mechanically force the shell to conform to the 1% diameter tolerance window.
- Local profile controls: Sweep templates check for peaking deviations at weld seams to prevent premature fatigue failure.
- Integration of these three dimensional inspection steps ensures compliance with ASME VIII-1 and structural integrity.

Out-of-Roundness in Cylindrical Shells I

Circularity deviations (ovality, peaking, and flat spots) arise in rolled plates due to non-uniform bending, welding shrinkage of longitudinal seams, and gravity-induced sag during fabrication.

Out-of-Roundness in Cylindrical Shells II

Key Points

- ASME Section VIII Division 1, paragraph UG-80, mandates that the difference between the maximum and minimum inside diameters at any cross-section shall not exceed 1% of the nominal diameter.
- For vessels subjected to external pressure, circularity is even more critical, governed by UG-80(b) charts to prevent buckling under compressive loads.
- Out-of-roundness creates localized bending moments under internal pressure, leading to stress concentration and accelerated fatigue crack propagation.
- Traditional measurement methods like chord-template gauges or simple diametrical calipers are insufficient for detecting localized peaking at weld seams.

Principles of the Swing Arm Method I

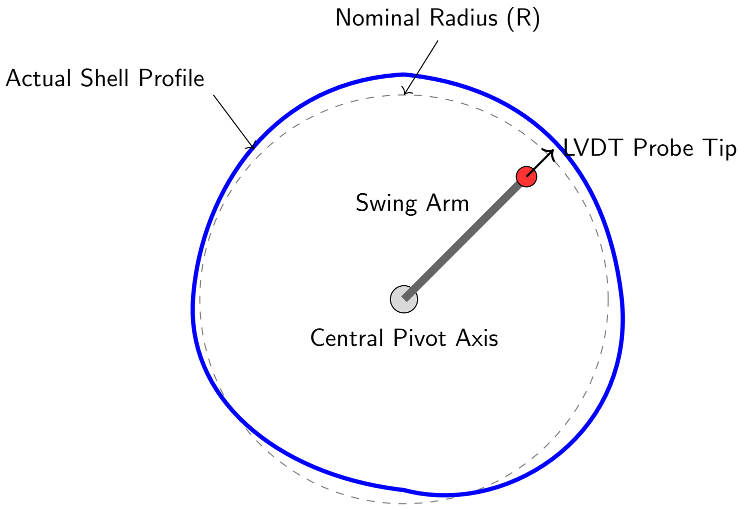
The swing arm method is a precision contact metrology technique suitable for medium-to-large cylindrical vessels, providing a continuous radial profile relative to a highly stable central axis.

Principles of the Swing Arm Method II

Key Points

- A central shaft or spindle is aligned exactly along the theoretical longitudinal axis of the cylindrical shell, supported by a rigid base or tripod.
- A radial arm of adjustable length is mounted on the spindle, carrying a high-precision dial indicator or Linear Variable Differential Transformer (LVDT) at its tip.
- As the arm is rotated 360 degrees, the contact probe tracks the internal or external surface, registering deviations from the nominal radius.
- Spindle runout and base stability are critical; any eccentricity in the spindle axis introduces a first-order harmonic error (apparent eccentricity) in the measured profile.

Swing Arm Metrology Setup Diagram I



Swing Arm Metrology Setup Diagram II

Key Points

- The diagram illustrates the contact probe (LVDT) scanning the inner surface of an out-of-round shell.
- Radial deviations are mathematically expressed as delta r(theta) = r(theta) - R_nominal, which are subsequently plotted on a polar chart.
- A Fourier analysis of the resulting delta r(theta) profile isolates ovality (2nd harmonic), lobing (3rd harmonic), and spindle alignment errors (1st harmonic).

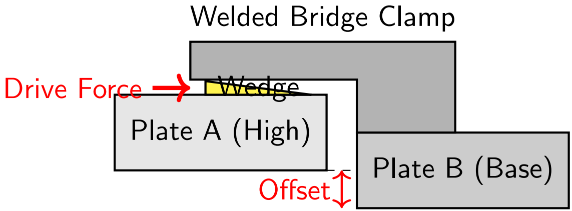
Joint Offset and Alignment Rectification by Wedge I

During fit-up of plate shells, mismatch (offset) at longitudinal and circumferential seams must be controlled to ensure stress flow. ASME UW-33 restricts offsets to a fraction of plate thickness (e.g., $t/4$ or 1.5mm max).

Key Points

- If plate edges do not align, a localized step or offset occurs, introducing bending stresses under tensile load and reducing the joint efficiency.
- A common mechanical rectification method uses temporary 'dogs' (bridge clamps) welded to one plate and spanning across the joint.
- A high-hardness tapered steel wedge is driven beneath the bridge to force the protruding plate edge down into alignment with the adjacent plate.
- Wedges must be driven systematically; excessive force or heavy hammering on high-tensile steels can cause local deformation, micro-fracturing, and work hardening.

Wedge Offset Rectification Diagram I



Wedge Offset Rectification Diagram II

Key Points

- The bridge clamp is welded to Plate B (right) and spans across the joint gap onto Plate A (left).
- Driving the wedge increases the downward force on Plate A, reducing the offset until the plates are co-planar.
- After rectification and tack welding, the bridge is removed via carbon arc gouging or grinding, followed by magnetic particle testing (MT) of the tack areas.

Strip Cladding and Weld Overlay Processes I

Cladding and weld overlay are deposition techniques used to apply a layer of corrosion-resistant alloy (CRA) onto structural carbon steel or low-alloy steel base metal, optimizing cost and corrosion resistance.

Strip Cladding and Weld Overlay Processes II

Key Points

- Unlike traditional wire electrodes, strip cladding uses a thin metal strip (typically 30mm, 60mm, or 90mm wide, and 0.5mm thick) as the consumable.
- Submerged Arc Strip Cladding (SASC) uses a granular flux to shield the arc, yielding a dilution of 15% to 25% with the base metal.
- Electroslag Strip Cladding (ESSC) replaces the arc with a conductive molten slag; resistance heating of the slag melts the strip, offering lower dilution (8% to 15%) and higher deposition rates.
- Typical overlay materials include austenitic stainless steels (309L for the barrier layer, 347 or 316L for the top layer) and nickel alloys (Inconel 625).

Metallurgical Quality Control in Weld Overlay I

Successful overlay cladding requires strict control of dilution, heat input, and microstructural phase balance to prevent cracking and corrosion resistance loss.

Metallurgical Quality Control in Weld Overlay II

Key Points

- Dilution refers to the percentage of base metal melted into the cladding layer. High dilution introduces iron into the overlay, reducing chromium and nickel concentration.
- Use of over-alloyed filler metal (e.g., 309L with 24% Cr, 12% Ni) in the first pass compensates for iron dilution, maintaining a corrosion-resistant surface.
- Post-weld heat treatment (PWHT) parameters must be restricted; excessive soaking time can cause carbon migration from the carbon steel base into the stainless steel, causing sensitization.
- Quality inspection includes ultrasonic testing (UT) for debonding/disbonding at the interface, and ferrite number measurements (typically 4 to 10 FN) to prevent hot cracking.

Limpet Coil Design and Layout Helix Calculation I

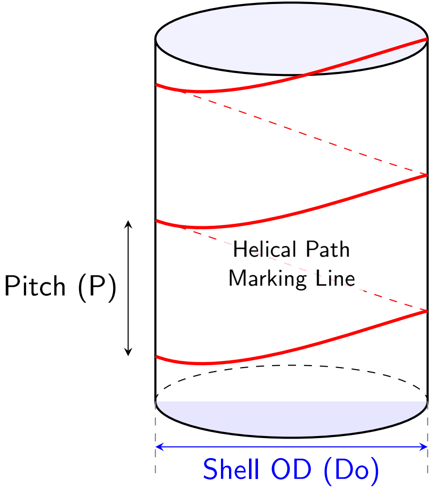
Limpet coils, or half-pipe jackets, require precise mathematical layout to ensure uniform heat transfer while preventing welding defects and interference with vessel nozzles.

Limpet Coil Design and Layout Helix Calculation II

Key Points

- Coil Geometry: Typically fabricated from carbon steel or stainless steel pipes split longitudinally at the centerline, creating a semi-circular cross-section.
- Pitch Calculation: Helix pitch is dictated by heat transfer area requirements and weld clearance (typically 75mm to 150mm spacing between coils).
- Helix Angle Formula: The helix angle is defined by the relation: theta = arctan(Pitch / (pi * Outer Diameter of Shell)).
- Circumferential Reference Lines: The shell is divided into 4, 8, or 12 longitudinal lines to plot coordinates for the helical path.
- Clearance Limits: Under ASME Section VIII Division 1, a minimum distance of 50mm or 3 times the plate thickness must be maintained between the coil weld and

Helical Path Marking and Layout Diagram I



Helical Path Marking and Layout Diagram II

Key Points

- Coordinate Marking: Points are plotted at the intersection of longitudinal generator lines and helical height levels ($h_n = n * P / N$).
- Layout Template: Flexible steel templates or wrapping papers are wrapped circumferentially to verify the accuracy of the marked helix line.
- Soapstone Marking: Soapstone or heat-resistant markers are used for final scribe lines, followed by center punching for permanence during welding.
- Obstacle Handling: If a nozzle is encountered, the coil is terminated with a pipe cap or transitioned into an adjacent bypass loop.

Longitudinal Seam (Long Seam) Fit-Up & Assembly I

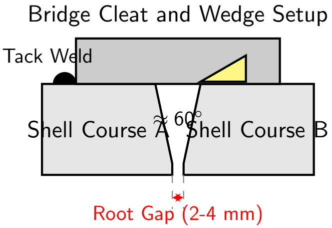
Longitudinal seams in shell courses bear double the hoop stress compared to circumferential seams. Code compliance under ASME Section VIII Div 1 UW-33 is critical for structural safety.

Longitudinal Seam (Long Seam) Fit-Up & Assembly II

Key Points

- Edge Preparation: Plate edges are beveled using flame cutting, plasma cutting, or machining to form V, U, or double-V profiles per WPS.
- Alignment Tolerance (UW-33): For plate thicknesses up to 3/4 inch (19mm), the maximum offset is 1/4 of thickness or 1/8 inch (3.2mm), whichever is smaller.
- Tack Welding: Carried out by certified welders using bridge tacks (cleats) to allow thermal contraction and prevent weld root cracking.
- Run-on/Run-off Plates: Welded at both ends of the seam to ensure stable arc and full penetration weld profile at the plate edges.
- Roundness Check: The shell section ovality is checked

Shell Fit-Up and Alignment Methods I



Shell Fit-Up and Alignment Methods II

Key Points

- Bridge Cleats: Rigid C-clamps or steel plates welded to one shell course and bridging the joint to maintain planar alignment.
- Wedge Insertion: Tapered steel wedges are driven under the bridge cleat on the un-tacked side to level the surfaces and remove offset.
- Root Gap Control: Maintained uniformly along the seam using spacer wires or gauges to ensure complete joint penetration.
- Tack Removal: Tack welds are progressively ground out or incorporated into the root pass during automated or manual welding.

Dish End to Shell Course Fit-Up I

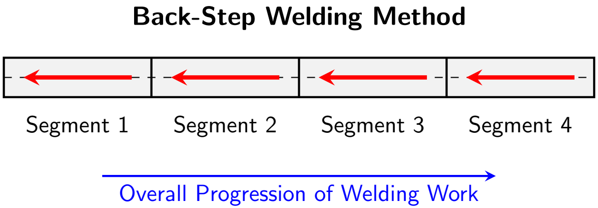
Assembling dish ends to shell courses requires managing circular mismatch caused by manufacturing tolerances and the thinning of the dish knuckle region during forming.

Dish End to Shell Course Fit-Up II

Key Points

- Straight Flange (SF): Dish ends must have a minimum straight flange length (typically 25mm to 50mm) to move the circumferential weld seam away from knuckle stresses.
- Thickness Transition (ASME UW-9): If wall thicknesses differ by more than 1/4 of the thinner section, a 3:1 taper joint must be machined on the thicker plate.
- Internal Alignment Spiders: Heavy internal spider rings with radial screws are used to round the shell course edge to match the dish ID.
- Offset Verification: Gap and alignment are measured at multiple locations (usually 8 to 16 equal intervals) using dial indicators.
- Back-Gouging: The root pass is gouged using carbon arc cutting (CAC-A) from the reverse side to reach

Back-Step Welding Sequence Diagram I



Back-Step Welding Sequence Diagram II

Key Points

- Local Shrinkage Control: Welding each segment in the opposite direction of the overall progression balances longitudinal stresses.
- Thermal Stress Minimization: By keeping the heat input distributed, this sequence reduces total angular and rotational distortion.
- Application to Shell Seams: Highly effective for both longitudinal and circumferential vessel joints, preventing seam opening/closing.
- Weld Reinforcement: Ensures overlap between segments is consolidated, minimizing start-stop defect concentration.

Methods to Control Thermal Distortion I

Thermal distortion during vessel welding is mitigated through mechanical restraint, thermal management, design optimizations, and strict welding sequences.

Methods to Control Thermal Distortion II

Key Points

- Mechanical Restraints: Strongbacks, stiffening rings, and internal spiders are kept in place until welding and subsequent cooling are complete.
- Pre-setting / Pre-bending: Plates are set with an opposing angle before welding, allowing weld contraction to pull them into alignment.
- Balanced Heat Input: Two welders working simultaneously on opposite sides of longitudinal or circumferential joints cancel out distorting forces.
- Limpet Coil Welding Sequence: Welds are deposited in staggered segments (e.g., quadrant sequencing) to balance fillet-weld shrinkage moments.
- Post-Weld Heat Treatment (PWHT): Stress relief at 600-650 degrees C (for carbon steels) relaxes residual stresses, restoring dimensional stability.

Introduction to Dish End Geometry I

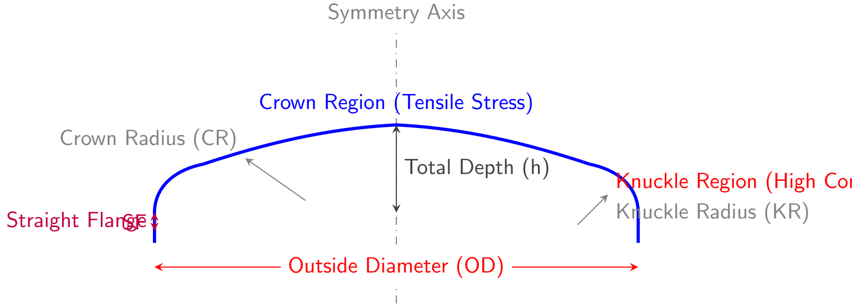
Dish ends (or heads) are end closures welded to the cylindrical shells of pressure vessels, storage tanks, and reactors. Their shapes are designed to optimize stress distribution under internal pressure, where transition regions experience complex bending and membrane stresses.

Introduction to Dish End Geometry II

Key Points

- Hemispherical Heads: Strongest geometry, handles twice the pressure of torispherical heads of equal thickness, but highest manufacturing cost.
- Ellipsoidal Heads: Typically a 2:1 ratio (major:minor axis), common in pressure vessels operating above 15 bar, offering a good balance of strength and depth.
- Torispherical Heads: Consist of a crown radius (CR), a knuckle radius (KR), and a straight flange (SF). Most common for low-to-medium pressures due to ease of fabrication.
- Flat Heads: Used for low-pressure or atmospheric storage vessels, requiring significant thickness to resist bending moments.

Dish End Profiles and Stress Regions I



Dish End Profiles and Stress Regions II

Key Points

- Knuckle Region: The high-curvature zone connecting the crown to the straight flange; experiences high localized compressive stress and potential buckling.
- Crown Region: The spherical center portion with large radius; primarily subjected to tensile membrane stresses.
- Straight Flange (SF): Prevents the weld seam between the head and shell from being located in the high-stress transition zone (knuckle).
- ASME Sec VIII Div 1 (UG-32) mandates minimum knuckle radius (6% of CR for torispherical heads) to prevent localized mechanical failure.

Dish End Forming Processes: Pressing & Spinning I

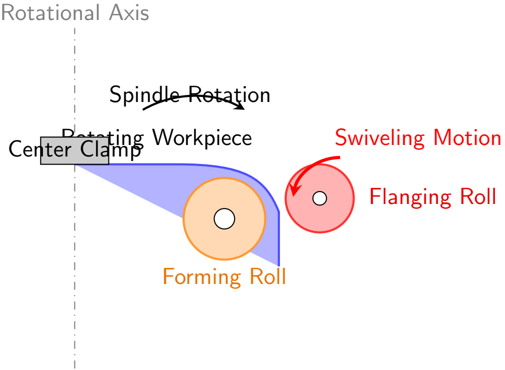
Industrial manufacturing of dish ends uses two primary processes: cold/hot hydraulic pressing (for forming the crown spherical profile) and flanging/spinning (for forming the knuckle and straight flange). Process selection depends on diameter, thickness, and material composition.

Dish End Forming Processes: Pressing & Spinning II

Key Points

- Pressing: Uses a hydraulic press (usually double-acting) to stamp the central crown profile. Can be done cold for thin/ductile metals, or hot (above recrystallization temp) for thick plates.
- Spinning (Flanging): A rotary forming method where the pressed crown is rotated on a vertical axis, and rollers shape the knuckle radius against a template.
- Cold Forming: Cost-effective, leaves no thermal scale, but causes work hardening which may require post-form heat treatment.
- Hot Forming: Reduces forming force, eliminates work hardening, preferred for thick plates (> 50 mm) or alloy steels prone to cracking.

Flanging Machine (Spinning) Operation I



Flanging Machine (Spinning) Operation II

Key Points

- Forming (Backing) Roll: Positioned inside the head; acts as the internal mandrel corresponding to the target knuckle radius.
- Flanging (Working) Roll: Mounted on a hydraulic swivel arm; applies continuous external pressure to bend the blank edge over the forming roll.
- Support Rolls: Placed underneath the blank perimeter to prevent sagging and vibration during high-speed rotation.
- Centering Device: Ensures the blank remains concentric with the spindle axis, preventing dimensional asymmetry and thickness variations.

Step-by-Step Fabrication Sequence I

A rigorous manufacturing sequence is followed to ensure structural integrity and compliance with design codes like ASME Sec VIII or EN 13445.

Step-by-Step Fabrication Sequence II

Key Points

- 1. Plate Preparation: CNC oxy-fuel or plasma cutting of raw plates. For large heads, segment plates (petals) are welded together.
- 2. Weld Seam Preparation: Plates are welded with SAW (Submerged Arc Welding). Reinforcements must be ground 100% flush to prevent stress risers and tool damage during pressing.
- 3. Blank Cutting: The welded assembly is cut into a perfect circular blank based on calculated blank diameter (including stretch allowance).
- 4. Crown Pressing & Flanging: The blank is pressed into a dome and flanged in a spinning machine to create the knuckle and straight flange.
- 5. Post-Forming Heat Treatment: Thermal stress relief (annealing or normalizing) to restore ductility and

Vessel Types & End Cap Selection I

The selection of dish end type is directly dictated by the vessel's primary function, operating pressure, temperature, and internal media behavior.

Vessel Types & End Cap Selection II

Key Points

- Pressure Vessels: Designed under ASME Section VIII. Typically utilize 2:1 ellipsoidal or hemispherical heads to handle high internal pressures safely without excessive wall thickness.
- Storage Vessels: Designed under API 650/620 or ASME Section VIII (for low-pressure LPG/LNG). Often use shallow torispherical or conical heads, or flat bottoms for atmospheric tanks.
- Reaction Vessels (Reactors): Used in chemical processing, often containing agitators, heating/cooling jackets (limpet coils). Typically use torispherical or ellipsoidal heads to facilitate optimal mixing flow patterns.
- Nozzle Integration: Openings in vessel heads must be reinforced according to ASME Sec VIII UG-37 to

Quality Control, Tolerances, and Defect Mitigation I

Defect prevention and rigorous testing are mandatory for safety-critical components operating under high pressures.

Key Points

- Thinning Allowance: Pressing and spinning cause material stretching. Designers must specify a nominal thickness that accounts for 10-15% thinning at the knuckle region.
- Out-of-Roundness: Head circumference and ovality must be within strict tolerances (typically $< 1\%$ of nominal diameter) to ensure proper fit-up with the shell.
- Profile Verification: Sweep templates (gauges) are used to verify that the internal crown and knuckle profiles do not deviate from design geometries.
- Defects & Detection: Common defects include cracking in the knuckle (detected by Dye Penetrant/Magnetic Particle Testing) and thinning/lamination (detected by Ultrasonic Testing).

Shell & Tube Heat Exchanger Anatomy & Standards I

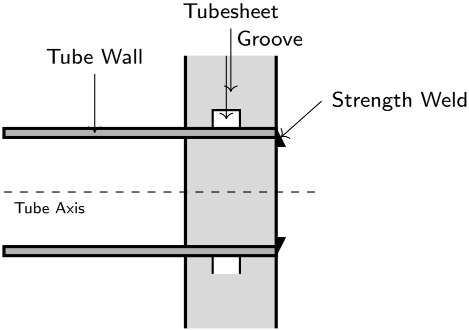
Overview of engineering design standards and primary pressure-retaining components.

Shell & Tube Heat Exchanger Anatomy & Standards II

Key Points

- Governed primarily by ASME Section VIII Division 1 for pressure vessel design and TEMA (Tubular Exchanger Manufacturers Association) standards.
- TEMA Class R specifies severe requirements for petroleum and processing; TEMA Class C for general moderate applications; TEMA Class B for chemical processes.
- Crucial components include the cylindrical shell, tubesheet (stationary and floating), channels/heads, channel covers, and transverse baffles.
- Longitudinal shell seams are typically welded using Submerged Arc Welding (SAW) to achieve deep penetration and high-quality deposition rates.

Tube-to-Tubesheet Joint Configuration I



Tube-to-Tubesheet Joint Configuration II

Key Points

- Mechanical tube expansion involves cold-working the tube against the tubesheet hole, creating a residual compressive stress field that acts as a seal.
- Tubesheet holes are machined with annular expansion grooves (width 1/8 in, depth 1/64 in) to provide mechanical locking and prevent axial tube pull-out.
- Strength welding is typically executed via mechanized GTAW (TIG) to provide a hermetic seal and mechanical strength, often followed by a light expansion pass.
- Joint integrity is inspected using pneumatic tests, helium mass spectrometer leak detection, or liquid penetrant inspection (LPI) on weld passes.

Internal support structures and thermal-hydraulic flow optimization.

Baffles, Tie Rods, and Shell Assembly II

Key Points

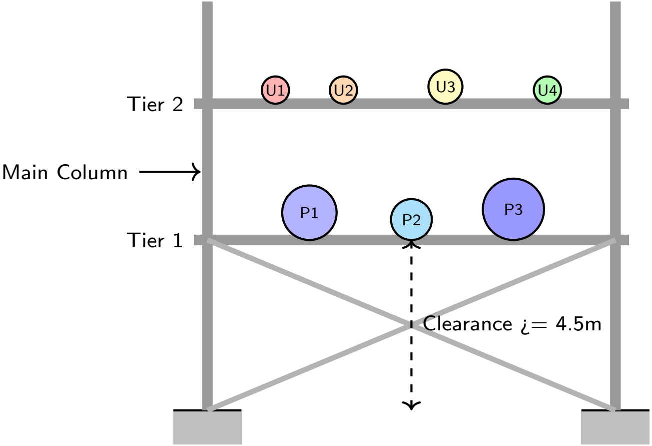
- Segmental baffles are cut vertically or horizontally (typically 15% to 45% of shell diameter) to guide fluid flow perpendicularly across the tube bundle.
- Baffle spacing (pitch) must prevent tube sagging and avoid flow-induced vibration, which can lead to tube-to-tube collision or fatigue failure.
- Tie rods and spacers run longitudinally between the tubesheets to secure the baffles in place and maintain precise axial spacing prior to tubing.
- An impingement plate is placed under the shell-side inlet nozzle if fluid velocity exceeds TEMA erosion limits, protecting tubes from direct fluid impact.

Prefabricated piping systems for industrial fluid transportation.

Key Points

- A piping spool is a prefabricated assembly of pipes, elbows, tees, and flanges, detailed in isometric drawings and designed for easy field installation.
- Fabrication complies with ASME B31.3 (Process Piping Code) and utilizes PFI (Piping Fabrication Institute) ES-3 for dimensional tolerances.
- Welding involves Gas Tungsten Arc Welding (GTAW) for the critical root pass to ensure full penetration, followed by SMAW or GMAW for filler passes.
- Dimensional tolerance for spool length is restricted to +/- 3.2 mm (1/8 in), and flange face alignment must not deviate by more than 1.6 mm from perpendicular.

Multi-Tier Pipe Rack Arrangement I



Multi-Tier Pipe Rack Arrangement II

Key Points

- Multi-tier steel pipe racks are designed to maximize space; generally, utility piping is on the top tier, and process piping is on lower tiers.
- Heavy lines and high-temperature lines are placed closer to the supporting structural columns to minimize horizontal beam bending moments.
- Thermal expansion is accommodated through U-shaped loops, offset bends, and guides that allow controlled axial displacement while preventing buckling.
- Standard vertical clearance under the rack cross-beams is maintained between 4.5 to 6.0 meters to allow safe vehicle and maintenance crane access.

Industrial Shed Structural Fabrication I

Fabrication of portal frames, purlins, and bolted connections.

Industrial Shed Structural Fabrication II

Key Points

- Fabricated structural frames consist of built-up column and rafter sections using high-yield structural steel, conforming to AISC and IS 800 standards.
- Trusses (e.g., Pratt or Howe configurations) are constructed from double angles or rectangular hollow sections joined by welded steel gusset plates.
- Field splicing of rafters and columns uses high-strength structural bolts (ASTM A325 or ASTM A490) installed to target pre-tension using the turn-of-nut method.
- Surface preparation requires abrasive grit blasting to Sa 2.5 standard, followed by high-performance epoxy primers and polyurethane topcoats.

Electrical Power Transmission Towers I

Design and fabrication of self-supporting lattice steel towers.

Electrical Power Transmission Towers II

Key Points

- Transmission towers are self-supporting steel lattice structures designed for wind loads, ice loads, conductor tension, and broken-conductor torsional loads.
- Structural members are fabricated from standard equal-leg and unequal-leg angle sections using automated CNC punching, cropping, and drilling lines.
- All steel elements are hot-dip galvanized after fabrication in accordance with ASTM A123, ensuring a protective zinc coating of at least 85 microns.
- Tower prototype load testing is conducted on full-scale models at specialized test beds to verify design assumptions and joint slip under limit loads.

3.4 Safety Norms for Work at Heights I

Work at Heights: Safety Protocols, Regulatory Thresholds, and Inspection Requirements

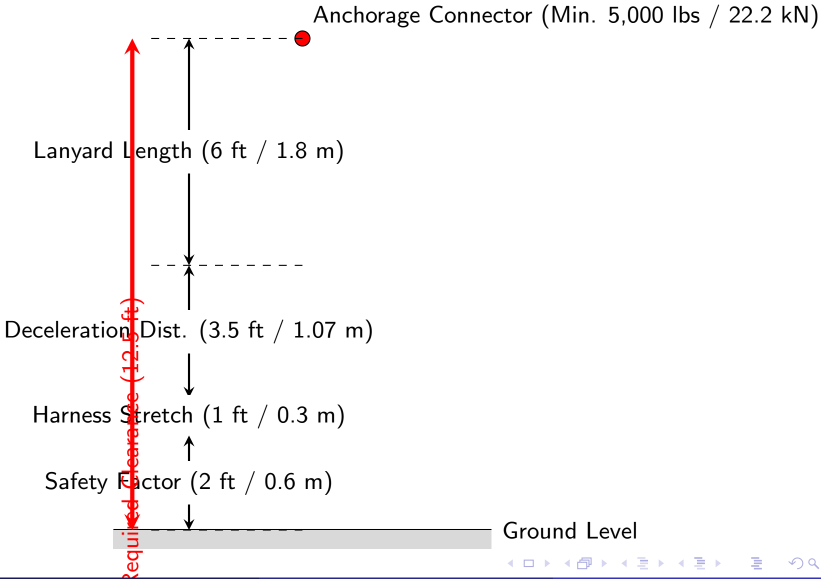
3.4 Safety Norms for Work at Heights II

Key Points

- Height Thresholds: OSHA 29 CFR 1926.501 mandates fall protection systems for work at heights of 6 feet (1.8m) or more above lower levels.
- Hierarchy of Fall Control: Elimination (performing work at ground level), Prevention (using guardrails, barricades, and scissor lifts), and Mitigation (deploying Personal Fall Arrest Systems).
- Pre-Work Structural Inspection: Mandatory inspection of scaffolding, ladders, anchorage points, and work platforms for structural integrity, corrosion, and proper assembly.
- Severe Weather Restrictions: Stop all work at heights during wind speeds exceeding 25 mph (40 km/h), rain, lightning, or icing conditions to prevent slips and falls.
- Emergency Rescue Plans: A written rescue plan must

Personal Fall Arrest System (PFAS) Clearance I

Personal Fall Arrest System (PFAS) Clearance II



Safety Norms BEFORE Welding Work I

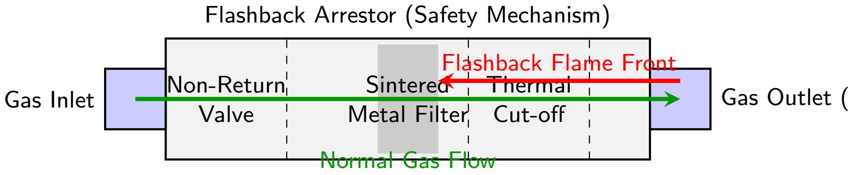
Pre-Welding Inspection, Workspace Preparation, and Hazard Mitigation Protocols

Safety Norms BEFORE Welding Work II

Key Points

- Hot Work Permit: Mandatory authorization outlining the scope of work, duration, designated fire watch, and gas-testing results.
- Atmospheric Testing: In confined spaces, test for combustible gases (must be $< 10\%$ LEL), toxic vapors, and oxygen levels (19.5% to 23.5%).
- Combustible Cleared Zone: All flammable materials, oils, and dry debris must be cleared within a 35-foot (10.7-meter) radius of the welding area (NFPA 51B).
- Equipment Inspection: Verification of ground clamps, undamaged insulation on welding cables, gas regulators, and flashback arrestors on gas cylinders.
- Ventilation Setup: Verification of local exhaust ventilation (LEV) or dilution systems to capture toxic fumes (hexavalent chromium, manganese, lead).

Flashback Arrestor Safety Mechanics I



Flashback Arrestor Safety Mechanics II

Key Points

- Safety Function: Flashback arrestors prevent the return of flame or gas mixture back into the hoses and regulators, preventing catastrophic cylinder explosions.
- Non-Return Valve (Check Valve): Stops the reverse flow of gas, ensuring that fuel and oxygen do not mix in the hoses.
- Flame Arrestor (Sintered Element): A porous metal structure that cools the flame front below its ignition temperature, extinguishing it instantly.
- Thermal Cut-off Valve: A spring-loaded valve that trips and shuts off the gas flow completely if the internal temperature exceeds a safe limit (typically around 100°C).

Safety Norms DURING Welding Work I

Active Hazardous Mitigation, Continuous Monitoring, and Electrical Safety Protocols

Safety Norms DURING Welding Work II

Key Points

- UV and IR Radiation Protection: Ensure welding screens (shade 10-14 rated) are positioned to protect surrounding personnel from arc flash and flash burn hazards.
- Electrical Hazard Control: Maintained dry workspace conditions; welder must stand on an insulating rubber mat if welding in damp environments to prevent electric shock from open-circuit voltage.
- Local Exhaust Ventilation (LEV): Position the LEV hood within one hood-diameter of the weld joint to ensure optimal capture velocity (typically 100-150 fpm) of toxic fumes.
- Cylinder Management: Gas cylinders must be stored upright in secured cylinder carts or chained to walls. Keep cylinders away from flying welding sparks and hot

Safety Norms AFTER Welding Work I

Post-Hot Work Procedures, Cooling, Inspection, and Housekeeping

Safety Norms AFTER Welding Work II

Key Points

- Mandatory Fire Watch Duration: Maintain the fire watch at the welding site for a minimum of 60 minutes after welding is completed to detect smoldering fires (per NFPA 51B).
- Equipment Isolation and Bleeding: Turn off welding machines, close all gas cylinder valves, bleed regulator pressures to zero, and coil all cables neatly.
- Hot Metal Identification: Mark all recently welded joints with 'HOT' using chalk or soapstone to prevent contact burns by subsequent shifts or workers.
- Visual and NDI Inspections: Perform post-weld inspections for defects (cracks, undercut, porosity) only after the weldment has cooled to ambient temperature.
- Waste Disposal: Safely dispose of used electrode stubs, slag chippings, grinding wheel remnants, and empty

Personal Protective Equipment (PPE) for Welding I

Standard PPE Selection Matrix and Specifications for Fabricators

Personal Protective Equipment (PPE) for Welding II

Key Points

- Welding Helmet: Must comply with ANSI Z87.1. Filter lens shade selection: Shade 10-11 for SMAW (Stick) <150A, Shade 12-14 for high current GTAW/GMAW.
- Flame-Resistant Body Protection: Heavyweight, flame-resistant (FR) cotton clothing or leather welding jackets. Avoid synthetic fibers (polyester, nylon) which melt when exposed to sparks.
- Welding Gloves: Heavy-duty, long-cuffed chrome-tanned leather welding gloves (welding gauntlets). Thin goatskin gloves are permitted only for low-current GTAW (TIG) for dexterity.
- Footwear: Leather safety boots (ASTM F2413 rated) with steel-toe caps, metatarsal guards, and slip-resistant soles. Trouser cuffs must cover boot tops to prevent catching hot slag.