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Brazing Processes and Equipment Operation

*Iván García Arrizabalaga
CESOL*



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Agenda Overview



- Flame Brazing: Process, Applications, and Safety
- Induction Brazing: Technology, Process, and Safety
- Furnace Brazing: Controlled Atmospheres and Process Management
- Special Brazing Processes: Techniques and Applications



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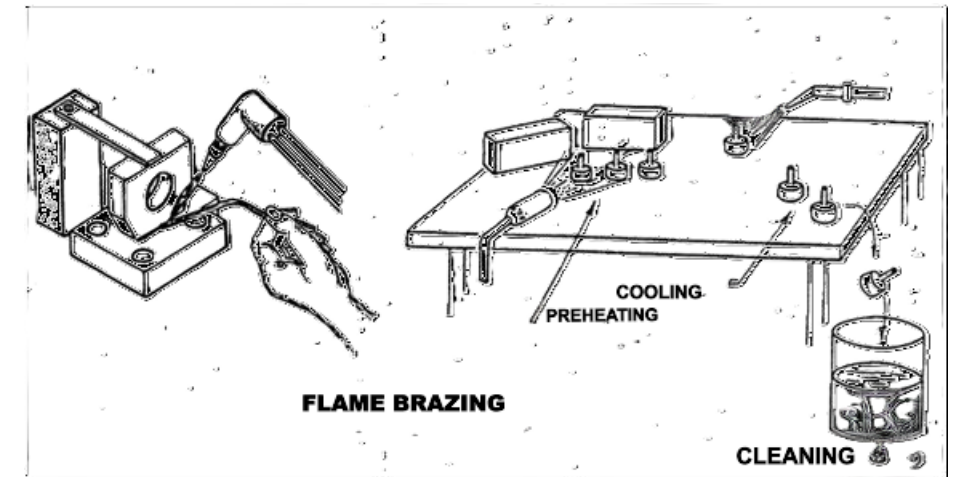
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Flame Brazing: Process, Applications, and Safety

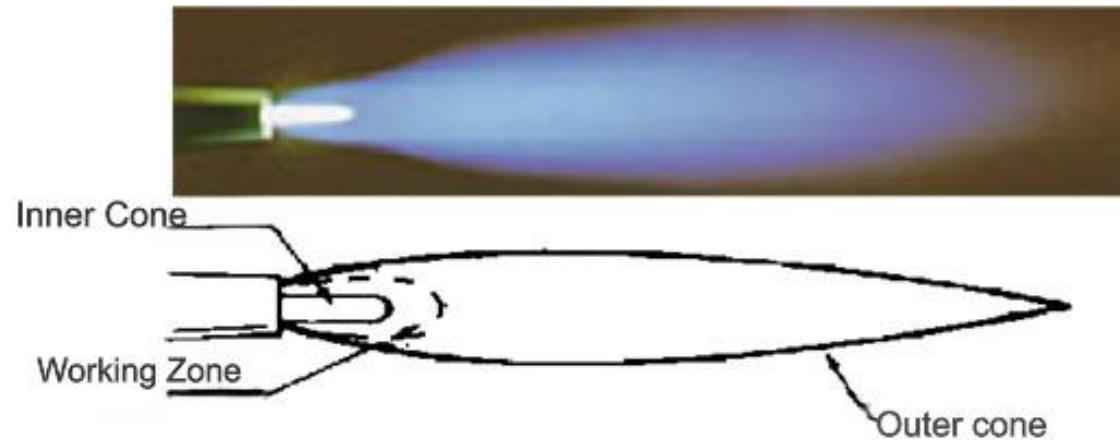
Flame Brazing

- Flame brazing is an established and versatile process for joining metals.
- This method uses an external flame—typically from the combustion of a fuel gas and oxygen—to heat the joint area and melt the filler metal.
- The molten filler is drawn into the joint by capillary action, bonding the base materials without melting them.
- Main advantages include low equipment cost, high adaptability, and suitability for a wide range of joint geometries.
- The operator controls the flame to ensure even heating and to avoid overheating, oxidation, or distortion.



Characteristic Zones of the Flame

- **Inner Cone:** Is the most distinctive feature of the oxy-acetylene flame.
- **Working Zone:** In front of the cone lies the most critical part of the entire flame, known as the working or soldering zone. Unfortunately, this area cannot be identified visually
- **Outer Cone:** In the outer cone, combustion of all the products that were not burned earlier with the oxygen from the air takes place.



Types of Flames by Combustion Gas



- **Oxy-acetylene flame:** Highest flame temperature (up to $3,480^{\circ}\text{C}$); versatile and easily adjusted for carburising, neutral, or oxidising conditions; neutral flame commonly used for most brazing to preserve joint integrity.
- **Oxy-hydrogen flame:** Lower temperature (about $2,700^{\circ}\text{C}$); gentle, pale blue flame ideal for delicate assemblies and sensitive alloys; excess hydrogen minimises oxidation risks.
- **Oxy-propane flame:** Moderate temperature (around $2,800^{\circ}\text{C}$); broad, soft heat zone suitable for brazing copper alloys and large or low-melting-point workpieces; economical and stable, preferred for large-scale jobs.
- Each flame type offers distinct advantages depending on the material, joint size, and sensitivity to heat or oxidation.

Types of Flames by Composition

- **Carburizing flames (excess fuel)** are used to minimize oxidation, ideal for steels and oxidation-sensitive metals, but may introduce unwanted carbon.
- **Neutral flames (balanced fuel and oxygen)** are preferred for most brazing tasks, providing stable heat and preserving material integrity without chemical changes.
- **Oxidizing flames (excess oxygen)** are suitable for metals that form stable oxides, such as some copper alloys, but can cause embrittlement if not carefully controlled.
- Correct flame selection and precise adjustment are crucial for high-quality brazed joints, preventing contamination and ensuring proper filler metal flow.



Step-by-Step Procedure

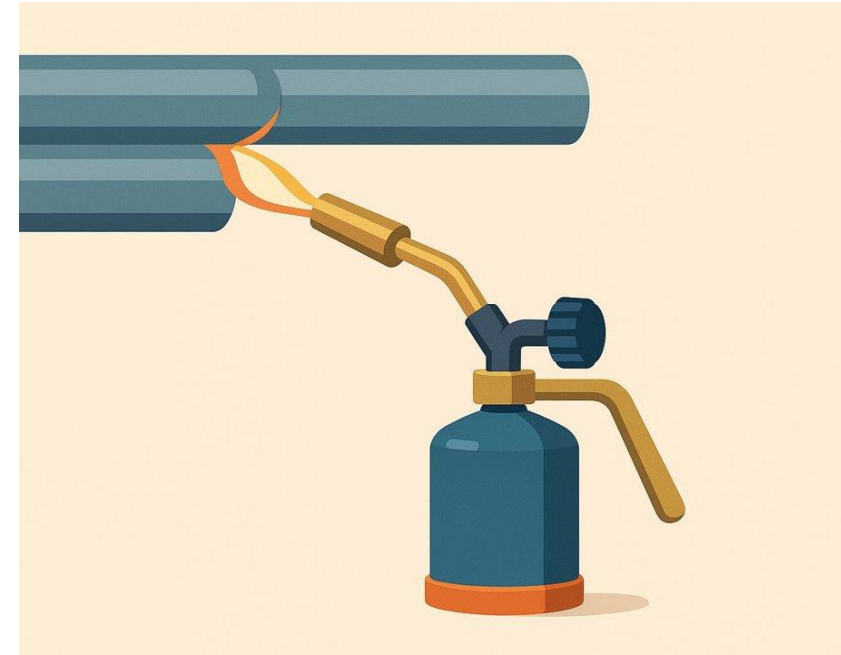


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1. Thoroughly **clean all surfaces** to remove oxides, grease, oil, and contaminants, using chemical, thermal, or mechanical methods. Avoid polishing; a slightly roughened finish is best for filler flow.
2. **Align and position components securely.** Ensure the joint gap fits the chosen materials and filler, typically 0.05–0.2 mm for effective capillary action.
3. **Apply flux** evenly to the joint area to dissolve oxides and promote wetting. Ensure enough flux to protect the joint throughout heating, taking care to prevent flux entrapment.
4. **Heat the assembly** with a torch set to the correct flame type (usually neutral), focusing on the joint and using a moderate rate to avoid shock or distortion.
5. **Introduce the filler metal** once brazing temperature is reached, allowing it to flow into the joint by capillary action. Apply by hand or pre-place as needed.
6. Allow the **assembly to cool gradually** to reduce thermal stress and distortion. Rapid cooling may be used for flux removal if suitable for the assembly.
7. **Remove all flux residues** after brazing, using the appropriate method for the flux type, and dispose of residues according to regulations.

Applications

- Flame brazing is widely used to join ferrous and nonferrous metals in industries such as piping, HVAC, and tool manufacturing.
- Common applications include repairing pipes, assembling copper and brass fittings, bicycle frame construction, and machinery maintenance.
- This process is ideal for on-site repairs and custom fabrication due to its portability and low setup requirements.
- Flame brazing is especially valuable for small batches, field work, and situations where flexibility is needed.
- Its adaptability allows use in both industrial and maintenance environments.



Advantages and disadvantages



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Advantages	Disadvantages
Low initial equipment cost	Labor-intensive
Accessible for a variety of settings	Requires skilled operators for consistent results
Highly flexible, accommodates diverse joint types, shapes, and materials	Lower productivity compared to automated brazing methods
Suited for small batch sizes or repair work	Higher risk of joint oxidation, distortion, or incomplete penetration if not carefully controlled
Portable, can be used in the field or maintenance situations	Efficiency and reliability affected in large volumes or stringent quality standards

Safety Considerations



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- **Use appropriate PPE:** Wear flame-resistant clothing, heat-resistant gloves, safety goggles, and respiratory protection to guard against burns and hazardous fumes.
- **Ensure proper ventilation:** Install local exhaust or mechanical ventilation to remove combustion gases and toxic fumes from the workspace.
- **Inspect and maintain equipment:** Regularly check hoses, torches, regulators, and safety devices for leaks or damage; follow standards and manufacturer guidelines.
- **Store and handle gases safely:** Secure cylinders upright, keep them away from heat sources, and use protective caps during storage and transport.
- **Train operators and prepare for emergencies:** Provide formal safety training, establish clear emergency protocols, and conduct regular safety drills for all staff.





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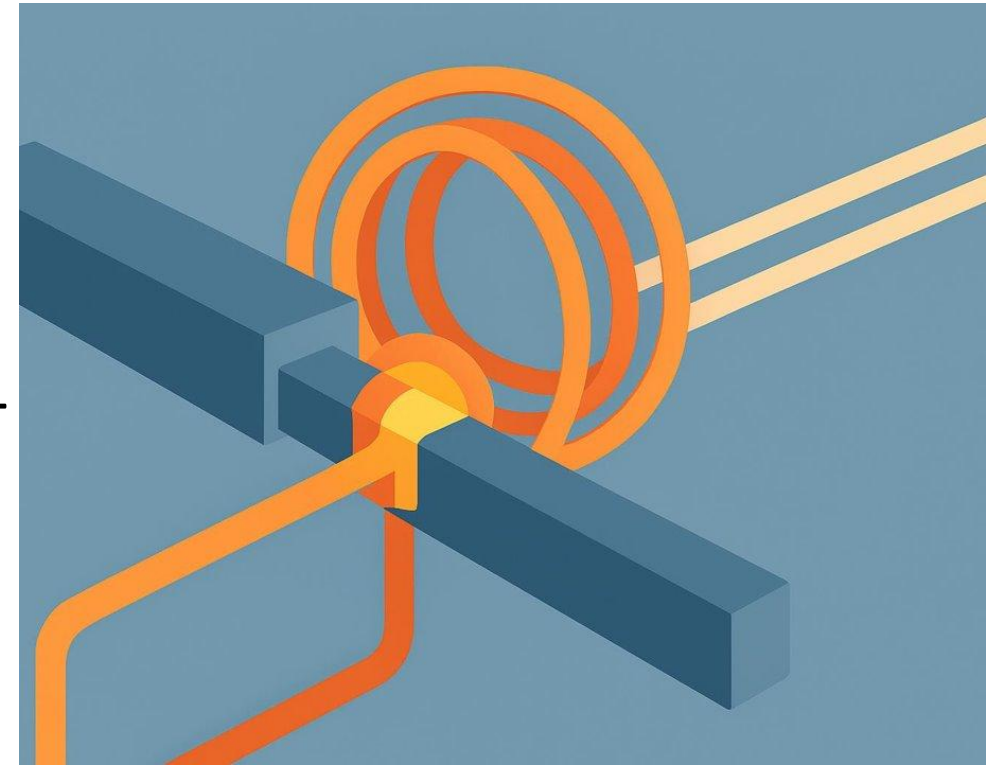
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Induction Brazing: Technology, Process, and Safety

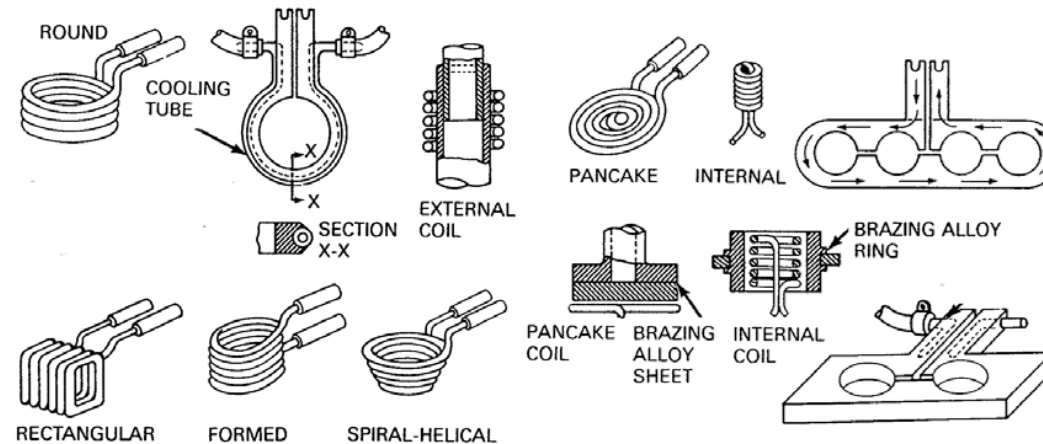
Induction Brazing

- Induction brazing uses electromagnetic induction to heat workpieces precisely at the joint area.
- Heat is generated internally by inducing eddy currents in the metal, not by external flames.
- The process enables rapid, localised heating with minimal thermal distortion of components.
- It is ideal for controlled, repeatable applications—suitable for automation and high-volume production.
- Compared to flame brazing, induction brazing offers greater efficiency and process control.



Principles of operation

- Heat for brazing is generated by induced electric currents in the workpieces.
- An alternating current flows through a nearby coil, creating these currents in the metal parts.
- The workpieces act like the secondary winding of a transformer, while the coil acts as the primary.
- Heating occurs through the Joule effect as the induced currents pass through the metal's resistance.
- The filler metal is positioned before the brazing operation starts.



Step-by-Step Procedure



- **Preparation:** Clean all surfaces and position the filler metal and flux (if required). The induction brazing cycle begins with thorough surface preparation to remove oxides and contaminants, ensuring proper wetting and flow of the filler metal. Flux is applied for brazing in air to prevent oxidation, though flux-free brazing is possible in controlled atmospheres.
- **Heating:** Energize the induction coil to induce localized heating in the workpiece. Once the assembly is ready, the induction coil is energized, and heat is induced in the workpiece.
- **Brazing:** The localized heating causes the filler metal to melt and flow into the joint by capillary action.
- **Cooling:** Controlled cooling is applied to avoid thermal shock and preserve dimensional accuracy. After brazing, controlled cooling is critical to prevent thermal shock and maintain dimensional stability.

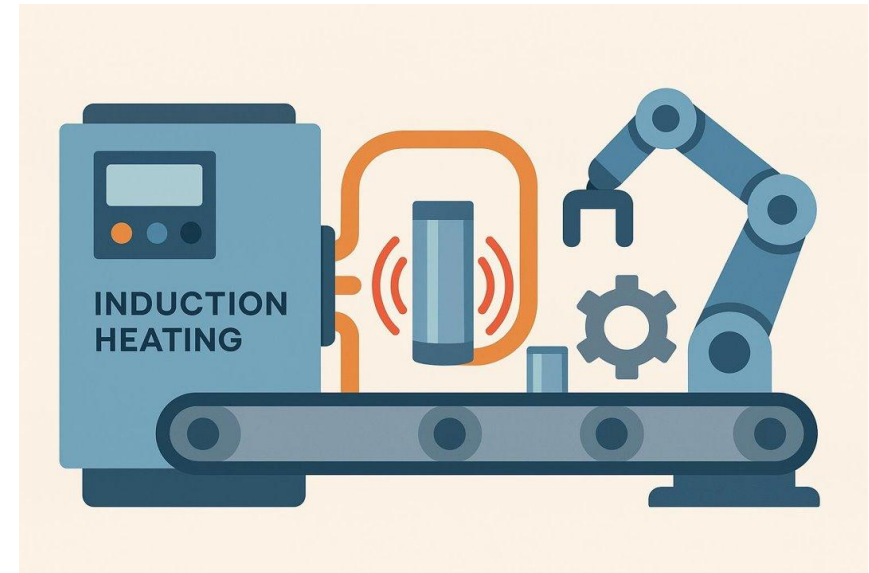
Technical Considerations



- **Coil and Joint Design:** A careful design of both the joint and the induction coil is necessary so that all areas of the joint reach the same temperature simultaneously.
- **Flux Use:** Flux is used unless the brazing is performed in a protective atmosphere that fulfills this function.
- **Frequency Selection:** The higher the frequency, the more superficial the induced currents are and, therefore, the more superficial the heating. If the brazed joint is located at or very close to the surface, higher frequencies can be used.
- **Penetration and Efficiency:** If very high frequencies and long times are used to allow the heat to penetrate, this will not only increase process costs but could also cause surface melting of the parts

Applications

- Induction brazing is commonly used in automotive, electrical, and tooling industries.
- It offers high precision, speed, and consistency in joining processes.
- Typical applications include brazing electrical connectors and carbide tool tips.
- Ideal for repetitive production environments requiring high repeatability.
- Supports efficient, automated manufacturing for various industrial components.



Advantages and disadvantages



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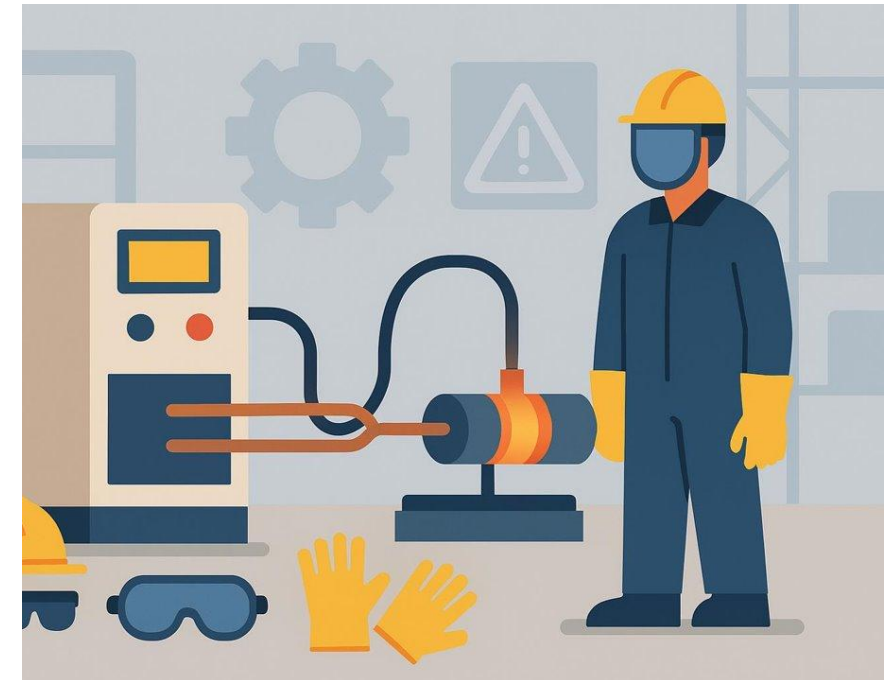
Limitations	Applications
High initial investment in equipment	Automotive, electrical, and tooling industries
Complex coil design required for irregular shapes or non-ferromagnetic materials	High precision, speed, and consistency in joining processes
Limited effectiveness on non-ferromagnetic metals without special accommodations	Brazing electrical connectors and carbide tool tips
Most effective on ferromagnetic materials; non-ferromagnetic metals may require special coil designs or alternative heating strategies	Ideal for repetitive production environments requiring high repeatability
	Efficient, automated manufacturing for various industrial components

Safety Considerations



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- High-frequency induction brazing poses risks of burns and electric shock; avoid direct contact with coils.
- Remove all metallic objects and jewellery before operation to prevent accidental heating.
- Ensure induction systems are properly grounded and inspect electrical connections regularly.
- Confirm cooling systems for coils are functioning to prevent overheating.
- Use PPE such as heat-resistant gloves and eye protection; keep the work area free from stray conductive materials.





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Resistance Brazing



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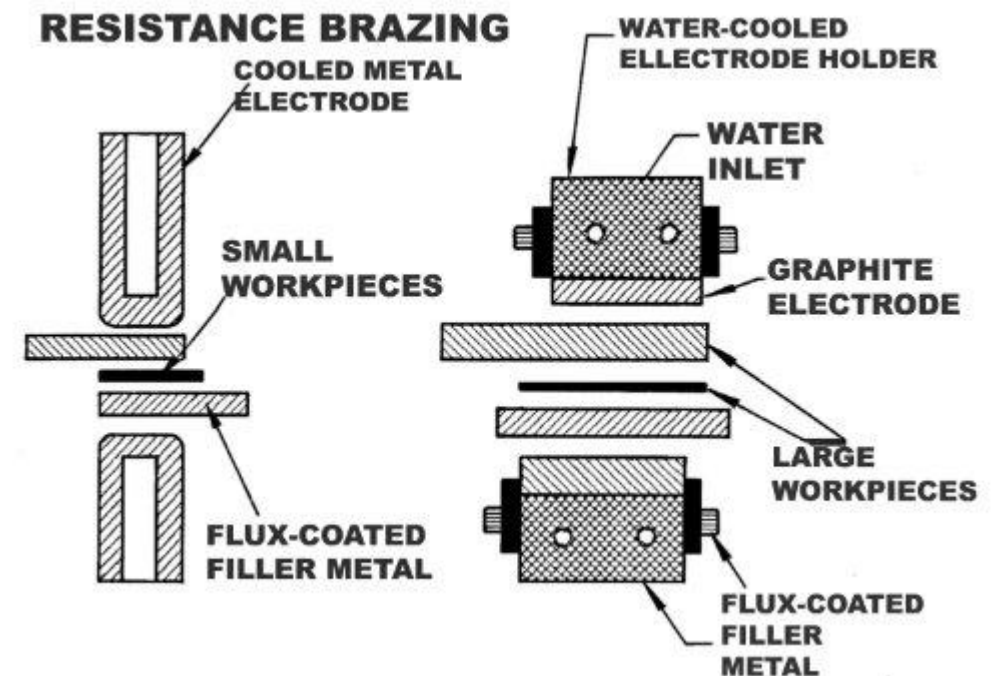


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Resistance Brazing: Principles and Equipment

- **Heat Generation by Electrical Resistance**
- Brazing heat is generated by electrical resistance from electrodes and parts forming the circuit. This heat is represented by Joules Law.

$$Q = I^2 R t$$

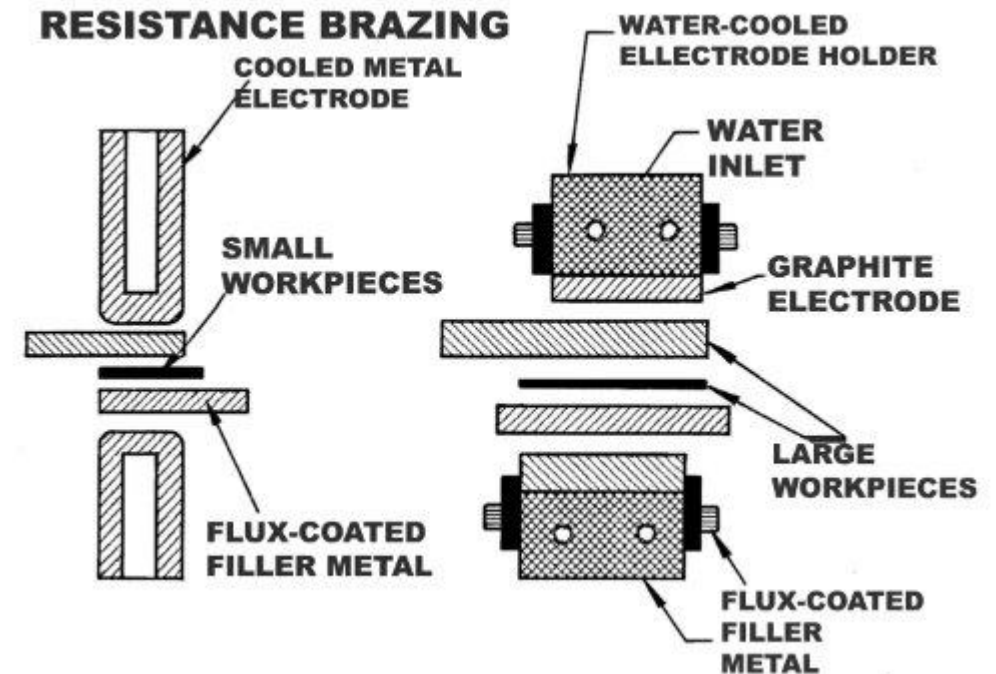




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Resistance Brazing: Principles and Equipment

- **Role of Flux and Atmospheres**
- Flux promotes electric current flow and sometimes atmospheres replace flux to prevent oxidation.
- **Brazing Equipment Setup**
- Equipment uses clamps with electrodes connected to a transformer, applying current and pressure simultaneously.
- **Process Control and Cooling**
- Proper current control prevents overheating; rapid cooling removes flux residues and solidifies the joint.





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Resistance Brazing: Principles and Equipment

Advantages	Limitations
Rapid, localized heating at joint area	Requires specialized equipment (water-cooled electrodes, high-capacity transformers)
Minimizes heat-affected zone	Significant initial capital investment
Reduces distortion or warping	Startup expenses can be prohibitive
Highly controllable temperature and pressure	Most effective for joints with limited area and simple geometry
Supports consistent, high-quality joints	Complex for larger or intricate parts
Suitable for repetitive production	Energy requirements escalate with joint size
Superior energy efficiency	High wear rate of graphite electrodes
Clean process with minimal oxidation	Flux can impact repeatability
Reduces post-braze cleaning	Clean contact surfaces essential
Compatible with automated systems	Contamination impedes current flow
Enhances productivity and repeatability	Selecting suitable flux is difficult
Well-suited to high-volume production	Not appropriate for high melting temperature materials
	Not economical for low-volume production



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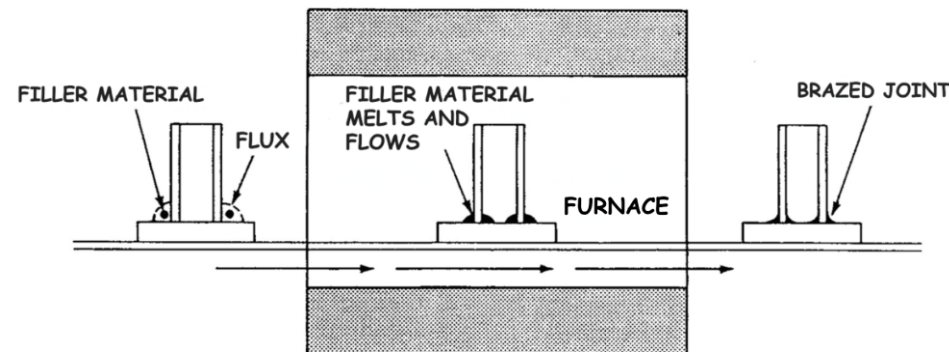
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Furnace Brazing: Controlled Atmospheres and Process Management

Furnace Brazing

- Furnace brazing heats entire assemblies uniformly in a controlled atmosphere or vacuum.
- Enables precise temperature control and simultaneous brazing of multiple joints.
- Ideal for complex or large-scale production due to consistent process repeatability.
- No direct flame is used; a sealed chamber prevents oxidation and contamination.
- Delivers high joint quality compared to torch or induction brazing methods.



Brazing Furnaces: Types



- **Vacuum Furnaces:** Employ a sealed chamber evacuated of air, eliminating the need for flux and preventing oxidation. Ideal for high-integrity, contamination-free joints.
- **Continuous Furnaces:** Feature moving belts or trays that transport assemblies through different temperature zones under controlled atmospheres, enabling mass production.
- **Bell Furnaces:** Use a removable cover to enclose the workpiece and control the atmosphere, suitable for batch processing.
- **Muffle Furnaces:** Incorporate a heating chamber separated from the workpiece, maintaining a controlled atmosphere and uniform heating.

Brazing Furnaces: Heating Methods



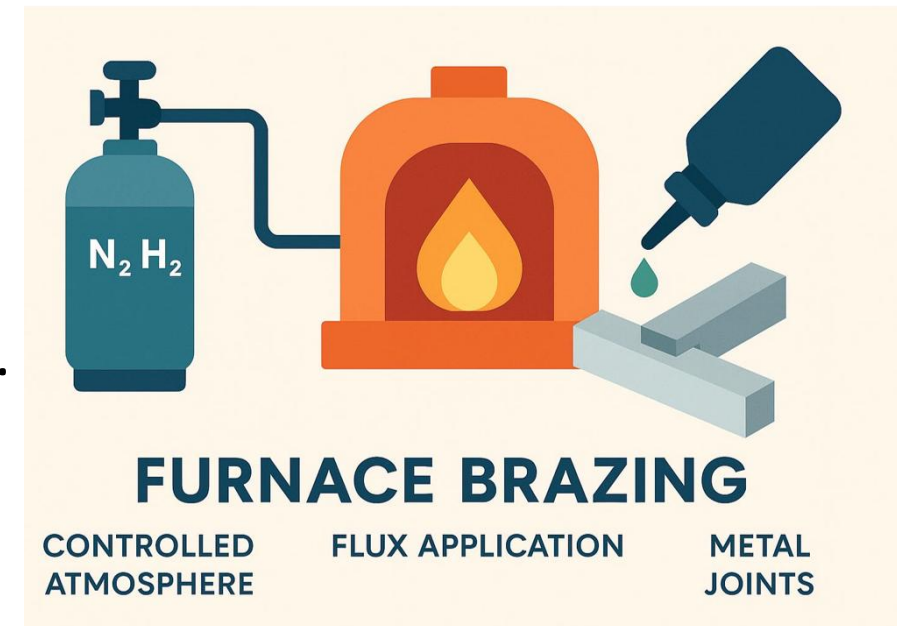
- Heating methods in furnace brazing include resistance, gas or liquid fuel, and induction heating.
- Flame heating should not contact parts directly to prevent localized overheating.
- Induction heating is increasingly adopted for precise and efficient heating.
- Precise temperature control ($\pm 6^{\circ}\text{C}$) is critical for uniform heating.
- Uniform heating minimizes distortion and ensures consistent brazing quality.

Atmospheres and Fluxes in Furnace Brazing



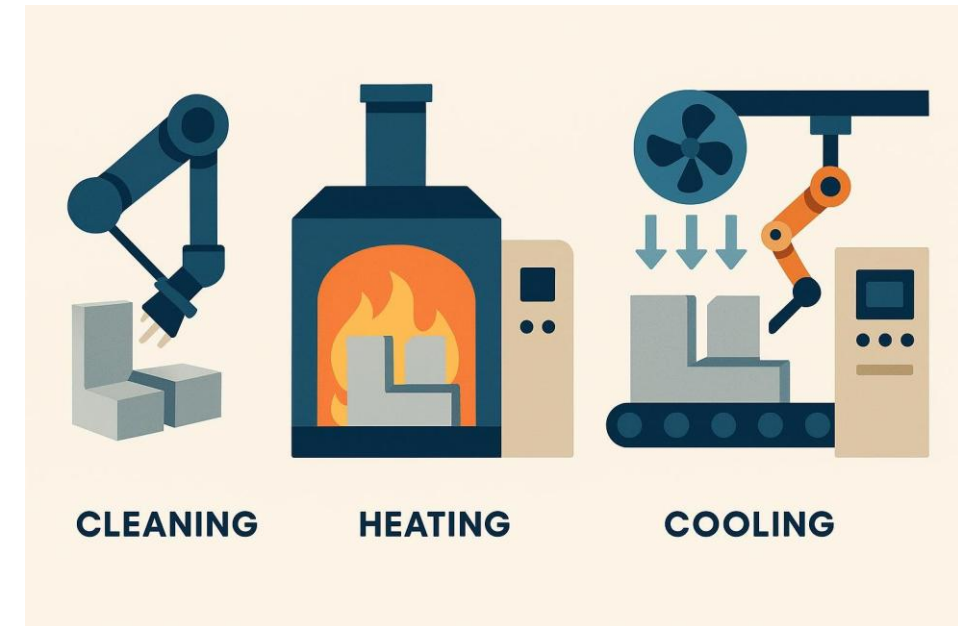
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- The furnace atmosphere critically affects brazed joint quality, influencing oxidation, contamination, and flux requirements.
- Vacuum or inert gas environments (argon, nitrogen) prevent oxidation, keeping metal surfaces clean and typically eliminating the need for flux.
- In air or partially inert atmospheres, flux is required to protect joint surfaces and ensure proper filler metal flow.
- Water-based fluxes require pre-drying components at 175–200°C for 5–15 minutes to avoid moisture-related defects like porosity or contamination.
- Careful selection and control of atmosphere and flux are essential for producing strong, reliable, and high-quality brazed joints.



Step-by-Step Procedure

- **Assembly Preparation:** Components must be thoroughly cleaned to remove contaminants, ensuring high joint integrity. The filler metal and flux (if required) are positioned at or near the joint.
- **Heating:** The entire assembly is uniformly heated to the brazing temperature. The time required depends on part thickness, mass, and fixture complexity. Once the brazing temperature is reached, the actual joining process usually takes 1–2 minutes; however, longer dwell times (up to 30–60 minutes) may be used to enhance alloy diffusion and improve ductility or strength.
- **Brazing:** In vacuum or controlled atmospheres, the filler metal melts and flows into the joint by capillary action, creating a strong, clean bond.
- **Cooling:** Controlled cooling prevents thermal shock and distortion, preserving joint integrity.
- **Post-Braze Heat Treatment:** Optional for certain materials to further enhance mechanical properties.



Technical Considerations



- **Coil and Joint Design:** A careful design of both the joint and the induction coil is necessary so that all areas of the joint reach the same temperature simultaneously.
- **Flux Use:** Flux is used unless the brazing is performed in a protective atmosphere that fulfills this function.
- **Frequency Selection:** The higher the frequency, the more superficial the induced currents are and, therefore, the more superficial the heating. If the brazed joint is located at or very close to the surface, higher frequencies can be used.
- **Penetration and Efficiency:** If very high frequencies and long times are used to allow the heat to penetrate, this will not only increase process costs but could also cause surface melting of the parts

Continuous Furnace Brazing



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- Continuous furnace brazing conveys components through a heated tunnel followed by a cooling zone.
- Process cycle time is controlled by conveyor speed and furnace temperature, usually lasting 15 minutes to 2 hours.
- Mainly used for brazing mild steel with copper filler material.
- Assemblies must be securely held and self-locating to avoid disturbance during movement.
- Conveyor speed is adjusted according to the mass of components for optimal results.

Advantages	Limitations
High throughput for production operations	Requires substantial capital investment, though less per unit output than vacuum furnaces
Usually does not require flux, eliminating the need for post-braze cleaning	Not practical for frequent start-stop operation
Components do not need to be as clean as those for vacuum brazing	
Enables the use of cost-effective brazing filler materials	

Batch Furnace Brazing



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- Batch furnace brazing involves loading components into a heated chamber with a protective atmosphere.
- The heating cycle is precisely controlled by adjusting furnace temperature.
- Rapid cooling is typically achieved by removing the retort from the furnace.
- No flux is usually required, reducing the need for post-braze cleaning.
- Commonly used in electronics and electrical industry applications.

Advantages	Limitations
Generally fluxless, with no need for post-braze cleaning	Longer process cycle times
Components do not need to be as clean as those for vacuum brazing	Retort life is limited at higher operating temperatures
Capable of processing larger components than continuous furnaces	High energy consumption

Vacuum Brazing



- Vacuum brazing takes place in a specialised, water-cooled furnace with a vacuum to maintain cleanliness and ensure filler flow.
- Precise control of temperature, heating, and cooling rates is possible, with accelerated cooling using inert gas circulation.
- This process is ideal for joining high-alloy steels, nickel alloys, and reactive metals, offering excellent corrosion and heat resistance.
- Processing times are relatively long, usually between 2 and 10 hours due to slow heating cycles.

Advantages	Limitations
Enables brazing of high-alloy steels, nickel alloys with titanium and aluminum, and reactive metals	High initial capital investment
Flux-free operation, eliminating the need for post-braze cleaning	Requires extremely clean component surfaces—more critical than with other brazing processes
Highly precise control of heating cycles and temperatures	Heating and cooling rates may not be optimal for all materials
Allows for combined brazing and heat treatment of the parent materials	Volatile metals must be excluded from the furnace charge, except when brazing aluminum

Applications



- Furnace brazing is essential for industries that require high precision and reliability, such as aerospace, automotive, and electronics.
- The process is ideal for mass production, allowing multiple joints to be brazed at once.
- Assemblies must be pre-positioned with filler metal and flux to ensure consistent results.
- Common applications include complex assemblies and electrical components.
- Furnace brazing delivers high repeatability and minimal distortion, meeting strict manufacturing standards.

Advantages and disadvantages



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Advantages	Limitations
Produces exceptionally clean, high-strength joints with minimal oxidation	Requires significant capital investment in specialized furnace equipment
Enables precise thermal control, reducing the risk of distortion	Longer cycle times compared to localized heating methods
Allows for simultaneous brazing of multiple joints, increasing productivity	Demands extremely clean surfaces for optimal results
Ensures repeatability and consistency, essential for high-performance manufacturing	Complex assemblies must be carefully fixtured to ensure uniform heating

Safety Considerations



- Install gas monitoring systems to detect leaks of inert or hazardous gases.
- Require operators to wear PPE: heat-resistant gloves, eye protection, and flame-resistant clothing.
- Implement emergency protocols, including safety interlocks and shut-off devices.
- Organize workspaces, keeping them free of stray conductive materials to prevent accidents.
- Perform regular maintenance and inspection of furnace systems for safe, reliable operation.



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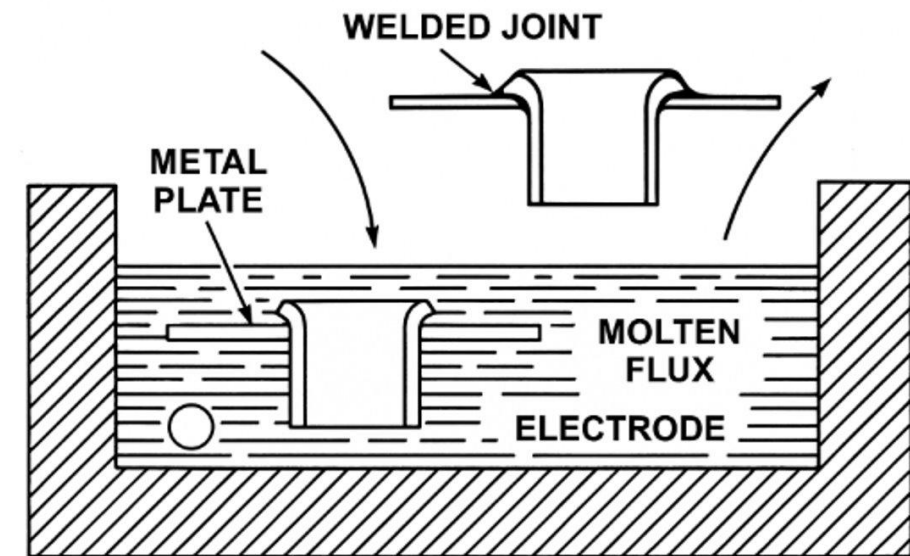
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Immersion Brazing: Types and Applications



Flux bath brazing

- Flux bath brazing (or flux dip brazing) is the most widely used immersion brazing method.
- Components are submerged in a bath of active molten flux, with filler material placed near the joint beforehand.
- This technique is mainly used for brazing aluminum and certain aluminum alloys at around 600 °C.
- It is effective for brazing multiple joints simultaneously in complex assemblies.
- Common applications include heat exchangers and similar components.



Flux bath brazing



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Advantages	Limitations
Provides precise and even heating of complex assemblies	Requires careful preheating of components
Allows for simultaneous heat treatment	Needs strict control of flux bath composition
	Provision for flux access and drainage is necessary
	Corrosive flux residues must be meticulously removed
	Parts may distort when heated close to their melting temperature



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Dip bath brazing

- Dip bath brazing immerses the joint area in molten filler, typically covered by molten flux.
- Primarily used for joining light section assemblies with limited heat capacity.
- Operating temperatures generally stay below 750 °C for flux stability.
- Not recommended for filler materials melting above 900 °C.
- Ideal for wire terminations and junctions, providing rapid and reliable joints.

Advantages	Limitations
Accommodates wide brazing gaps	Bath composition may drift and requires monitoring
Produces high-quality joints	Flux must be replenished frequently
Enables rapid heat transfer	Components need to be preheated
	Component surfaces are coated with filler material, which can be wasteful

Dip bath brazing



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- Salt bath brazing involves submerging assemblies in a fused salt bath, with filler material and flux applied before immersion.
- The method is now largely obsolete due to practical limitations and safety concerns.
- Mainly used for ferrous components, often combining brazing and heat treatment in one operation.
- Only specific filler materials (EN 1044, AG, CU3XX) with melting points above 750 °C are suitable.
- Process requires careful salt removal and disposal after brazing.

Advantages	Limitations
Ensures uniform temperatures and rapid heating	Requires preheating to dry the flux
Keeps components free from scale	Not suitable for light section parts due to floatation and surface tension effects of the salt
Allows for combined heat treatment and brazing	Salt removal and safe disposal can be problematic



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Special Brazing Processes: Techniques and Applications



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Laser Beam Brazing: Precision and Process Control

- **Precision Heat Source**
- Laser brazing uses a localized high-energy laser to precisely melt filler metal with minimal thermal impact.
- **High-Quality Joint Formation**
- Produces strong, low-distortion joints with excellent dimensional and surface quality, ideal for visible seams.
- **Process Parameters Control**
- Critical parameters like laser power, beam focus, and feed rate must be carefully monitored for consistent results.
- **Automation and Robotics**
- Laser brazing is well suited for automated production, enabling repeatability and integration in robotic systems.

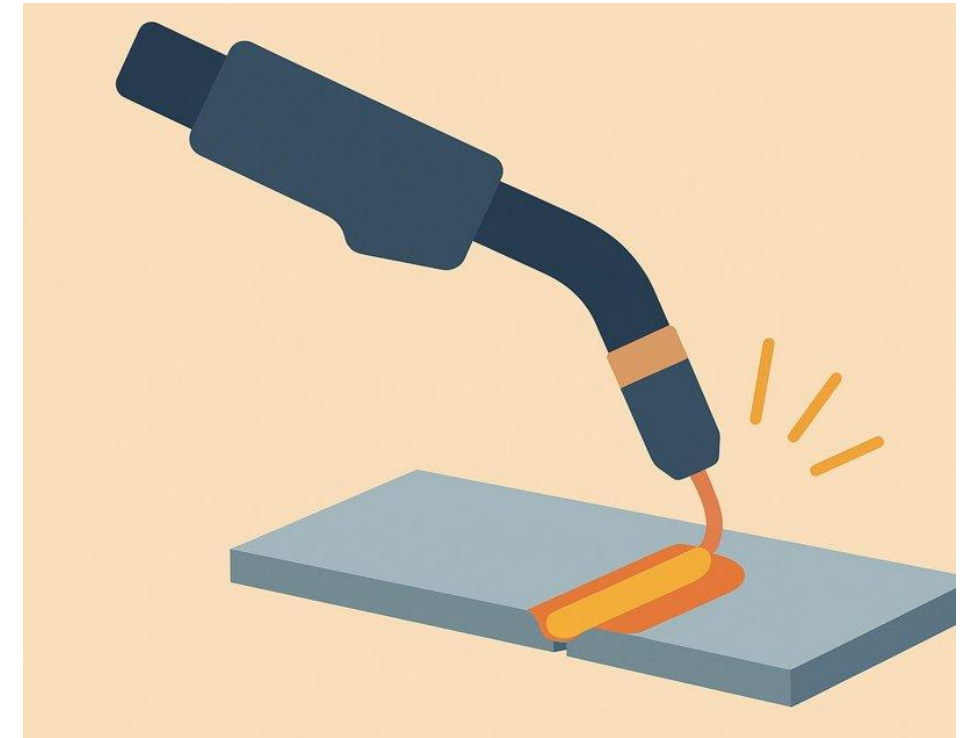




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Arc Braze Welding: MIG Brazing and Industrial Use

- **Arc Braze Welding Basics**
- Arc braze welding joins materials using an electric arc to melt filler metal without melting base metals.
- **MIG Brazing Technique**
- MIG brazing uses a continuously fed copper wire and electric arc to join coated steels precisely.
- **Benefits for Coated Steels**
- This method preserves protective coatings by reducing zinc evaporation, porosity, and distortion risks.
- **Industrial Applications**
- Arc braze welding is used in automotive and thin-sheet fabrication requiring precision and corrosion resistance.



Infra-red Brazing: Non-contact Heating and Applications



- **Infrared Heating Technology**
- High-intensity quartz lamps provide focused infrared radiation for precise and non-contact heating in brazing.
- **Non-contact Brazing Process**
- Infrared brazing heats metal surfaces uniformly without contact, enabling fast and controlled melting of filler metals.
- **Applications and Advantages**
- Used in electronics, automotive, and aerospace, infrared brazing minimizes thermal stress and oxidation for delicate materials.

Electron Beam Brazing: Vacuum Process and High-Precision Joints



- **Focused Electron Beam Heating**
- A focused beam of high-velocity electrons generates precise heat by converting kinetic energy at the joint area.
- **Vacuum Environment Benefits**
- Vacuum conditions prevent oxidation and contamination, providing clean, high-quality joints without flux.
- **Process Control Parameters**
- Controlling beam power, focus, speed, and filler feed is critical to avoid overheating and ensure precision.
- **Applications in High-Tech Industries**
- Commonly used in aerospace, nuclear, and medical fields for reliable, clean, and precise metal joints.

Iván García Arrizabalaga
igarcia@cesol.es



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