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CU AW 04: Introduction to brazing technology: Knowledge for high quality brazed joints

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1 Main Brazing Processes

In industrial brazing, the choice of process is critical to achieving reliable joints that meet functional and quality requirements. Each brazing method offers distinct characteristics in terms of heat application, joint integrity, productivity, and cost. Understanding these differences is essential for selecting the most appropriate technique for a given application.

The three primary processes widely used in industry are:

- **Flame Brazing** – A traditional method employing an oxy-fuel flame to heat the joint area. It is valued for its flexibility and low equipment cost but requires skilled operators and careful control to avoid oxidation and distortion.
- **Induction Brazing** – A modern technique that uses electromagnetic induction to generate localized heat. It offers high precision, rapid heating, and suitability for automation, making it ideal for repetitive production. However, it involves higher initial investment and design complexity for irregular shapes.
- **Resistance Brazing** – Another industrial technique that utilizes electrical resistance to generate heat directly at the joint interface. In this method, components are positioned between electrodes, and a controlled electric current passes through the contact area, producing localized heating and enabling the filler metal to flow and bond the materials. Resistance brazing offers high energy efficiency, precise temperature control, and minimal distortion, making it suitable for joining thin sections, dissimilar metals, or delicate assemblies. Its application is common in the electrical and electronics industries, where clean joints and accurate placement are essential.
- **Furnace Brazing (Vacuum Brazing)** – A process performed in a controlled atmosphere or vacuum, ensuring oxidation-free joints without flux. It is preferred for high-integrity components in aerospace, automotive, and electronics. Despite its advantages in quality and cleanliness, it demands significant capital investment and longer cycle times.
- **Immersion Brazing:** – This process involves submerging components in a bath of molten brazing alloy, allowing the filler metal to flow into joint areas by capillary action. Immersion brazing is particularly suited for achieving uniform heating and simultaneous joining of multiple parts, which makes it efficient for high-volume production runs. It is commonly applied in the fabrication of heat exchangers, radiators, and other assemblies with complex or numerous joints and is advantageous when consistent joint quality and throughput are critical.

Each process has **specific advantages and limitations** that influence its applicability in different industrial sectors. Factors such as joint design, material compatibility, production volume, and cost constraints must be considered when selecting the appropriate brazing method.

In the following sections, we will explore:

- Detailed descriptions of each process and its operational steps.
- Typical applications across industries.
- Comparative analysis of advantages and limitations.

This knowledge will enable professionals to make informed decisions, optimize brazing operations, and ensure compliance with international standards such as **UNE-EN 14324**, **ISO 22688**, and AWS recommendations.

1.1 Flame Brazing

1.1.1 Introduction

Flame brazing is one of the most established and versatile processes for joining metals. This technique employs an external flame, typically produced by the combustion of a fuel gas with oxygen, to heat the joint area and melt the filler metal. The molten filler flows into the joint by capillary action, bonding the base materials without melting them. Thanks to its adaptability, low equipment cost, and suitability for a variety of joint geometries, flame brazing is widely used for maintenance, repairs, and small to medium-scale manufacturing in industries such as HVAC, automotive, and metal fabrication.

In flame brazing, base metals are carefully prepared and assembled with correct clearances. An appropriate flux is applied to the joint area, and the assembly is heated with a controlled flame. The operator manipulates the torch to ensure uniform heating, allowing the filler metal to melt and flow into the joint by capillary action. Precise flame control is essential to avoid overheating, oxidation, or distortion. After brazing, controlled cooling and removal of flux residues are necessary to prevent corrosion and secure long-term durability.

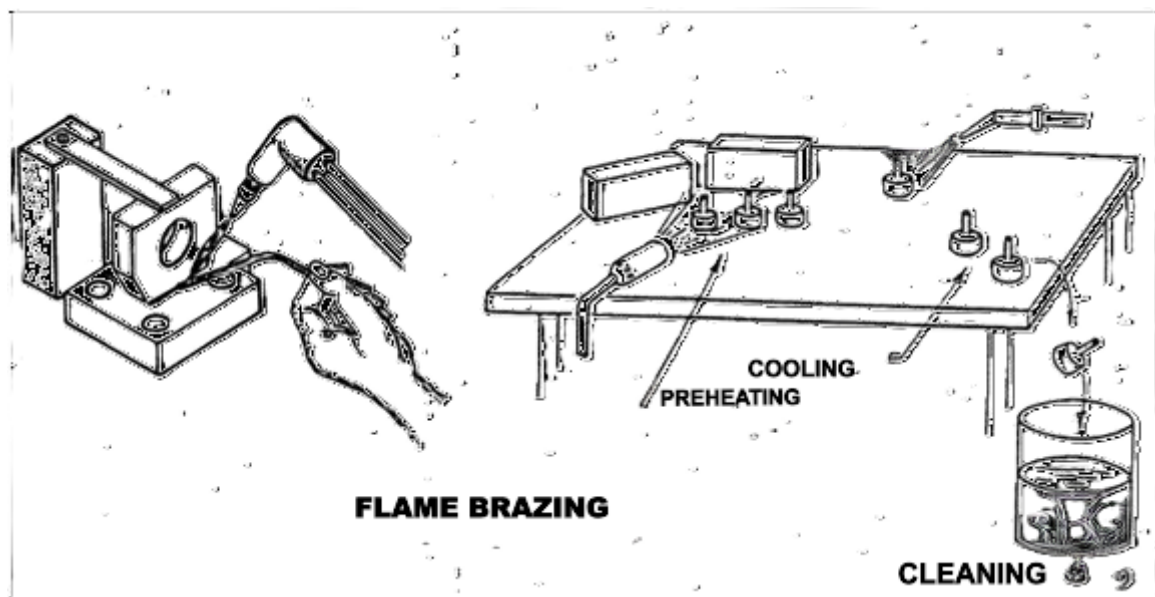


Figure 1 Flame brazing process description [1]

1.1.2 Types of Flames by Combustion Gas

- **Oxy-acetylene flame:** This is the most widely used flame in industrial flame brazing, capable of reaching the highest flame temperatures—up to approximately 6,300°F (3,480°C). Its intense, sharply defined white cone or "dart" is ideal for joining most metals. The oxy-acetylene flame offers excellent flexibility and can be easily adjusted to produce carburizing (reducing), neutral, or oxidizing conditions, depending on the needs of the base material and filler. The neutral flame is generally preferred for standard brazing operations, as it minimizes oxidation and maintains the metallurgical integrity of the joint.
- **Oxy-hydrogen flame:** This combination creates a lower flame temperature, around 4,900°F (2,700°C), with a pale blue flame. It is particularly suitable for brazing delicate assemblies, sensitive alloys, or materials prone to overheating. In practice, an excess of hydrogen is used to prevent oxidation due to the potential dissociation of water vapor at high temperatures. The oxy-hydrogen flame is valued for its gentle heating profile, reducing the risk of damaging thin or temperature-sensitive components.
- **Oxy-propane flame:** The oxy-propane flame provides a moderate temperature, about 5,100°F (2,800°C), and is characterized by a broader, softer heat zone. This makes it well-suited for brazing copper alloys, larger workpieces, or metals with relatively low melting points. While slower than oxy-acetylene, propane is more economical and offers stable combustion, making it a popular choice for large-scale brazing and cutting of softer metals.

1.1.3 Characteristic Zones of the Flame

The characteristic zones of the flame are as follows:

- **Inner Cone:** Is the most distinctive feature of the oxy-acetylene flame. It appears as a dazzling white area with a sharply defined outline, especially when acetylene is used as the fuel. However, it is not easily visible when hydrogen is used as the fuel.
- **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. It is the region of maximum temperature and is used to carry out the brazing or welding of the workpiece. Therefore, it is important to maintain a distance between the tip of the cone and the surface of the molten pool, typically between 2 and 5 mm, depending on the size of the flame and the torch being used.
- **Outer Cone:** In the outer cone, combustion of all the products that were not burned earlier with the oxygen from the air takes place. This prevents atmospheric oxygen from coming into contact with the metals being joined at high temperature, creating a protective atmosphere that prevents oxidation.

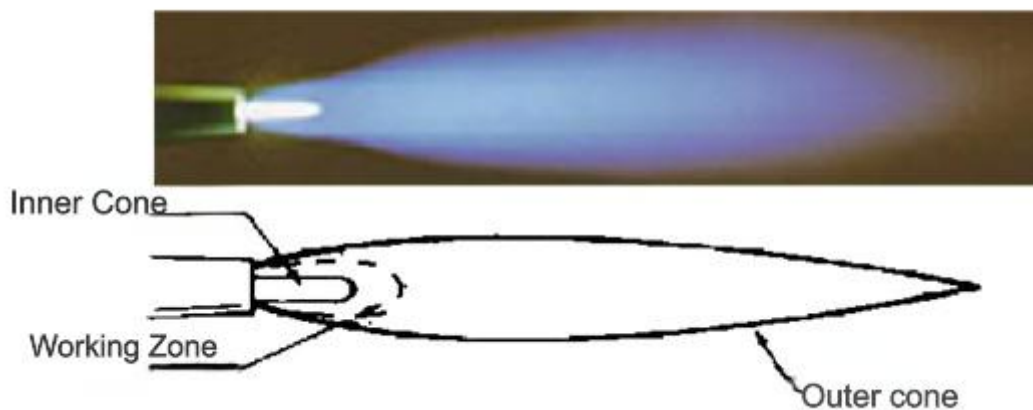


Figure 2 Characteristic zones of the flame

1.1.4 Flame Types: Carburizing, Neutral, and Oxidizing

The chemical nature of the flame—determined by the ratio of fuel gas to oxygen—is a critical factor in the success of brazing operations. Each flame type has distinct characteristics and is suitable for specific applications. Below is a detailed overview of the main flame types used in flame brazing:

- Carburizing (Reducing) Flame:** This flame is produced when there is an excess of fuel gas relative to oxygen. It is recognized by a longer, luminous inner cone and a pale greenish outer envelope, which appears due to the surplus fuel. The carburizing flame is ideal for brazing steels and situations where oxidation must be minimized. The reducing atmosphere helps prevent oxidation of the base and filler metals, but may introduce unwanted carbon into the joint, potentially affecting its properties. This type of flame is also used for brazing metals that are sensitive to oxidation or require a protective environment during heating.
- Neutral Flame:** The neutral flame is achieved when the fuel and oxygen are mixed in the correct proportions—neither in excess. It is characterized by a sharply defined white cone and the absence of a luminous envelope or colored penacho. This flame type is the standard choice for most brazing operations because it provides a stable thermal environment, minimizes oxidation, and preserves the metallurgical integrity of both the base and filler metals. The neutral flame does not alter the chemical composition of the materials being joined, making it suitable for a wide range of metals and alloys.
- Oxidizing Flame:** An oxidizing flame occurs when there is an excess of oxygen in the fuel mixture. It is identified by a shorter, narrower inner cone and a hissing sound at the torch outlet. While generally avoided for brazing steels due to the risk of excessive oxidation, this flame type can be used for brazing materials that form stable oxides—such as certain copper alloys or brass. The oxidizing environment helps create a protective oxide layer on the joint surfaces, but it can also cause embrittlement or loss of strength in some metals. Careful adjustment is required to prevent damage to the joint and surrounding areas.



Figure 3 Types of flame. From right to left. Carburizing, Neutral and Oxidizing flames

Choosing the correct flame type is essential for achieving high-quality brazed joints. Skilled operators must adjust the fuel-to-oxygen ratio precisely to match the requirements of the base and filler metals, joint geometry, and desired outcome. Using the appropriate flame helps avoid contamination, ensures proper wetting and flow of the filler metal, and prevents unwanted chemical reactions or physical distortion of the assembly.

1.1.5 Step-by-Step Procedure

1. Surface Preparation:

All components to be joined must be thoroughly cleaned to remove oxides, grease, oil, and other contaminants. Cleaning may be achieved by chemical, thermal, or mechanical means, such as degreasing, pickling, or scratch brushing. The surfaces within the joint should not be polished; a slightly roughened finish is preferable to promote filler metal flow. For certain materials, such as nickel alloys containing titanium or aluminum, or ceramics, it may be necessary to apply a suitable coating (e.g., plating or metallizing) to improve wettability. The degree of cleanliness required depends on the quality demands of the assembly and the brazing process to be used. For flux-free controlled atmosphere brazing, the highest level of preparation is required.

2. Assembly:

Align and secure the components, ensuring that the assembly gap (fit-up at room temperature) is appropriate for the materials and filler metal to be used. The typical joint clearance for capillary action is between 0.05 mm and 0.2 mm, but the optimum gap may vary depending on the filler material, parent materials, and brazing process. The assembly must be designed to maintain the required relationship between parts during brazing, using suitable methods such as jigs, fixtures, or self-locating features.

3. Flux Application:

Apply the chosen flux evenly to the joint area to dissolve oxides and promote wetting. Fluxes are essential when brazing in air, except when using self-fluxing copper-phosphorus filler materials on copper. The flux should be applied in sufficient quantity to protect the joint throughout the heating cycle. Fluxes may be in powder, paste, or liquid form, and can be applied manually or automatically. Care must be taken to avoid flux entrapment in the joint, which can lead to porosity or corrosion.

4. Heating:

Adjust the torch to the appropriate flame type, usually a neutral flame, and heat the assembly

evenly, focusing on the joint area. The torch should be manipulated to concentrate heat at the optimum working distance, typically just outside the inner combustion cone. For large assemblies, multiple torches may be used. The heating rate should be moderate to avoid thermal shock or distortion, and the temperature should be carefully controlled to reach the brazing temperature of the filler metal.

5. Filler Addition:

Introduce the filler metal once the joint reaches the correct brazing temperature, allowing it to flow into the joint by capillary action. The filler may be hand-fed as a rod or wire, or pre-placed as a ring, foil, or paste. The point of application can affect joint quality; internal pre-placement can help demonstrate complete capillary flow. The filler should be allowed to flow freely to fill the joint without excessive buildup.

6. Cooling:

Allow the assembly to cool gradually to minimise thermal stress and distortion. Rapid cooling may be used in some cases to facilitate flux removal, provided the assembly can withstand thermal shock. Controlled cooling is especially important for assemblies with dissimilar materials or complex geometries.

7. Post-Braze Cleaning:

Remove all flux residues after brazing to prevent corrosion. The method of removal depends on the flux type:

- For high-temperature borax-based fluxes, mechanical removal (e.g., grit or shot blasting) is required.
- For lower-temperature fluoroborate fluxes, residues can be removed with hot or boiling water, sometimes aided by agitation or ultrasonic vibration.
- Aluminium brazing fluxes require very careful removal due to their corrosive nature. Proper disposal of flux residues must comply with relevant regulations

1.1.6 Applications

Flame brazing is used in a wide range of sectors for joining ferrous and nonferrous metals. Examples include repair of piping systems, joining of copper and brass fittings in HVAC installations, assembly of bicycle frames, tool manufacturing, and field maintenance of machinery. Its portability and minimal setup requirements make it especially valuable for on-site repairs and custom fabrication.

1.1.7 Advantages and Limitations of Flame Brazing

Flame brazing offers several notable advantages, making it a popular choice in various settings. One of the key benefits is its low initial equipment cost, which allows for accessibility in a wide range of environments. The apparatus required for flame brazing is simple, and its operation is straightforward, enabling users to quickly learn and implement the process. Another advantage is the moderately rapid heating rate, which facilitates efficient work without compromising control.

The process is highly flexible, accommodating diverse joint types, shapes, and materials. This adaptability makes flame brazing particularly well suited for small batch sizes, repair work, and maintenance situations where portability and versatility are critical. The technique allows for maximum flexibility in terms of shape, size, heat pattern, and consumables, supporting both simple and complex assembly operations. Additionally, flame brazing requires minimal capital investment and maintenance, further enhancing its practicality for many users.

- Apparatus is simple and its operation is easily understood
- Moderately rapid heating rate
- Maximum flexibility of shape, size, heat pattern, and consumables for both simple and complex assembly operations
- Minimum capital investment
- Minimum maintenance

Despite its advantages, flame brazing presents several limitations. The process is labor-intensive, resulting in a high labor investment, and requires skilled operators to achieve consistent, high-quality results. Training is necessary to ensure consistent outcomes, as improper technique can lead to issues such as joint oxidation, distortion, or incomplete penetration. Productivity is generally lower compared to automated brazing methods, which can impact efficiency and reliability in large-scale or high-standard production environments. Health and safety factors are also more challenging to control, necessitating careful management to ensure safe operation.

- High labor content (investment)
- Training required for consistent results
- Relatively low production rate
- Health and safety factors are more difficult to control

The main constraints on the size of assemblies that can be brazed using the flame process are determined by the available equipment and the gas supply's capacity to provide the necessary heating energy. Additionally, the ability to dispose of surplus energy and manage pollution, such as heat splash and fumes, also imposes limits on the process.

1.2 Induction Brazing

Induction brazing is a highly efficient and precise joining method that utilizes electromagnetic induction to produce heat directly within the workpiece at the joint area. Unlike flame brazing, which relies on external application of heat via combustion, induction brazing generates heat internally by passing an alternating current through a custom-designed induction coil. This coil creates a magnetic field, inducing eddy currents in the conductive material of the workpiece, resulting in rapid and localized heating at the joint. The process is especially beneficial for applications that require controlled heating, minimal thermal distortion, and high repeatability, making it well suited for automated and high-volume manufacturing environments.

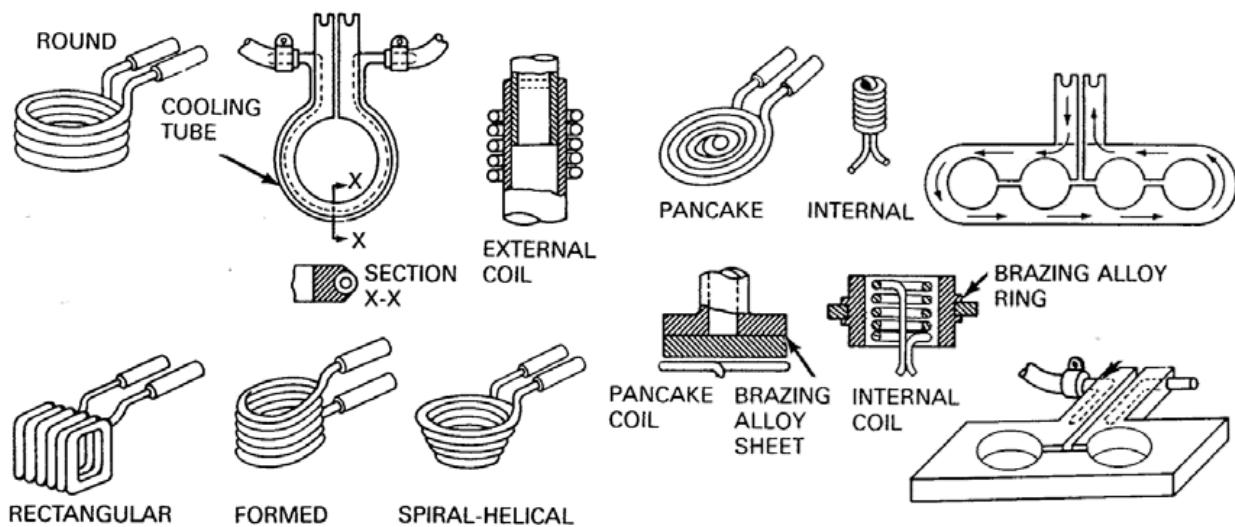


Figure 4 Examples of types of induction coils for brazing [1]

1.2.1 Principle of Operation

The heat required for brazing is obtained by induced currents in the parts to be joined. These electric currents are induced by a coil, located near the pieces to be joined, through which an alternating current flows. The workpieces are not part of the coil's electrical circuit, but act as if they were the short-circuited secondary of a transformer, in which the coil is the primary. Heating occurs due to the Joule effect as the induced currents pass through the electrical resistance of the metal parts. The filler metal is pre-positioned before the brazing operation.

1.2.2 Process Steps

1. **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. Components are assembled with the correct joint clearance, and the filler metal—often pre-placed as rings, shims, or preforms—is positioned at the joint. Flux is applied for brazing in air to prevent oxidation, though flux-free brazing is possible in controlled atmospheres.
2. **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.
3. **Brazing:** The localized heating causes the filler metal to melt and flow into the joint by capillary action.
4. **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.

1.2.3 Technical Considerations

Achieving successful induction brazing depends heavily on the proper design of both the coil and the joint. These elements must be engineered to ensure that all areas of the joint reach the necessary brazing temperature simultaneously. Uniform heating is essential for producing strong, reliable joints and avoiding defects that can arise from uneven temperature distribution.

Flux plays an important role in the brazing process. Unless induction brazing is performed in a controlled or protective atmosphere that prevents oxidation, flux is typically required. The flux cleans and protects the joint area, facilitating the smooth flow and wetting of the filler metal to ensure high-quality bonds.

The selection of operating frequency is another critical factor. Induction brazing generally utilizes high-frequency currents, typically within the range of 10 to 450 kHz. The chosen frequency determines the depth of heating: higher frequencies produce shallow, surface-level heating due to more superficial induced currents, making them ideal for joints near the surface. In contrast, lower frequencies penetrate deeper, making them suitable for joints located beneath the surface. However, prolonged use of very high frequencies can increase process costs and may risk surface melting of the workpieces.

The induction brazing process is designed for efficiency, especially in automated manufacturing environments. The entire brazing cycle is rapid, with the actual joining operation typically completed within seconds. This speed makes the technique well suited for high-volume production.

Induction brazing is versatile and can be applied across all temperature ranges to electrically conducting materials. It accommodates both single, ‘one-off’ operations and mass production of components with consistent shapes. The process can utilize either flux or a controlled atmosphere to promote successful brazing, with filler material and flux usually pre-placed prior to heating.

In advanced technological applications, components may be brazed in a vacuum or under a protective gaseous atmosphere to further enhance joint quality. For detailed guidance on power sources, coil design, process parameters, and automation, it is recommended to consult manufacturers who specialize in the design and production of induction brazing equipment.

1.2.4 Advantages and Limitations of Induction Brazing

Induction brazing is widely favored in high-volume manufacturing for its rapid, localized heating capabilities. This targeted application of heat significantly reduces cycle times and limits the exposure of surrounding materials to elevated temperatures. As a result, components experience minimal thermal distortion, helping to maintain precise dimensional accuracy within assemblies.

The process is highly reproducible and consistent, making it exceptionally well-suited for automated production environments where precision and repeatability are paramount. Another benefit of induction brazing is its energy efficiency, which lowers operational costs and supports sustainability objectives in large-scale manufacturing. Furthermore, heat is concentrated specifically in the joint areas, ensuring efficient use of energy and material resources.

- Rapid heating

- Closely controlled, reproducible heat patterns for simple shapes
- Economical to run
- Heat is concentrated in joint areas

Despite its strengths, induction brazing presents certain limitations. The process requires a substantial initial investment in specialized equipment, which can be a significant barrier for smaller manufacturers. The technology also relies on complex coil designs, particularly when working with irregularly shaped components or those made from non-ferromagnetic materials.

While induction brazing is most effective with ferromagnetic metals, its efficiency decreases with non-ferromagnetic materials, especially those with high thermal conductivity. In these cases, achieving adequate heating may require additional accommodations, such as custom coil designs or alternative heating strategies, increasing both the complexity and the cost of the process.

- High capital investment
- Less efficient for non-ferromagnetic materials, particularly those with high thermal conductivity
- Coil design is challenging for irregular or complex components

Induction brazing is typically used to heat only the specific area to be brazed. With careful design, this method can be applied to very large assemblies, as well as to extremely small components, demonstrating versatility in terms of component size.

1.2.5 Applications

Induction brazing is widely used in industries such as automotive, electrical, and tooling, where precision, speed, and consistency are essential. Typical applications include brazing electrical connectors, carbide tool tips, and components in repetitive production environments that demand high repeatability. In the automotive sector, induction brazing is utilized for joining fuel lines, heat exchangers, and sensor housings, as well as for assembling air conditioning components and other critical assemblies that require leak-tight, durable joints. In the aerospace industry, the process is often employed for joining turbine blades, honeycomb structures, and various high-strength alloys, where uniform heating and minimal thermal distortion are crucial for maintaining component integrity and meeting stringent quality standards.

1.3 Resistance Brazing

1.3.1 Process Description

Resistance brazing is a joining process in which heat is generated by the electrical resistance encountered as current flows through both the electrodes and the parts to be joined. In this technique, all components of the joint—including the workpieces and electrodes—become integral parts of the electrical circuit. Before the brazing operation begins, the filler material is carefully positioned at the joint area. The process relies on Joule heating, where electrical energy is converted to heat as current passes through a resistive material.

The parts to be joined are raised to the brazing temperature by the passage of a high current at a low voltage. Suitably shaped electrodes are used to ensure good electrical contact and to apply the necessary force to hold the component parts in the correct position for brazing. Heat may be generated indirectly within the body of the electrode—commonly made of graphite—from which it is transmitted by thermal conduction to the joint assembly. Alternatively, heat may be generated directly by the combined effect of various interfacial and bulk resistances of the parts themselves; in this scenario, water-cooled metal electrodes with high electrical conductivity are used to transmit current and maintain the appropriate holding force on the joint assembly.

This process is best suited to applications where joints of limited area and relatively simple geometry allow the electrodes to easily access the assembly. It is particularly effective for the repetitive brazing of flat, symmetrical components using either manual or automated techniques. The temperatures reached during resistance brazing vary depending on the heating mode: indirect heating is usually limited to temperatures below 800 °C due to excessive burning and wastage of the graphite electrode, whereas such limitations do not apply to direct heating.

The use of flux in resistance brazing requires careful consideration due to its non-conductive nature and the associated risk of explosion. As a result, self-fluxing brazing filler materials are preferred, or—less commonly—a localized protective atmosphere is used. Where flux is unavoidable, only a small quantity of thin paste or liquid flux is recommended. In most cases, a flux is applied to the joint surfaces before brazing. The choice of flux is important, as it must enable the flow of electric current during the process. However, most fluxes are insulative in their dry state and only become conductive when molten. Sometimes, a controlled atmosphere is used as an alternative to flux; if it can prevent oxidation and facilitate wetting, a separate flux may not be necessary.

The primary equipment used in resistance brazing consists of a pair of clamps or tongs, each ending in an electrode, and connected to a transformer that supplies the required current. To avoid excessive heating and potential damage, the clamps and electrodes are generally water-cooled. During the brazing cycle, both electrical current and mechanical pressure are applied simultaneously to the joint area, and this pressure is maintained until the molten filler metal solidifies, ensuring the joint remains secure. In some configurations, both electrodes are applied from the same side and direction, which requires a backing support to provide counter-pressure.

Like other precision joining techniques, such as induction brazing, resistance brazing requires careful process setup. The current must be adjusted to achieve rapid heating—sufficient to complete brazing within a short time—while avoiding excessive temperatures that could cause oxidation, melting of the base metal, or premature electrode deterioration. Once the joint is solid and structurally sound, assemblies are often rapidly cooled in water. This rapid quenching both solidifies the joint further and helps remove residual flux from the surfaces.

The design of components and assemblies must accommodate the need to apply current and pressure at elevated temperatures. Proper fixturing is essential to prevent deformation or collapse during the process. Overall brazing time can range from a few seconds to several minutes, depending on the size, mass, and complexity of the parts involved.

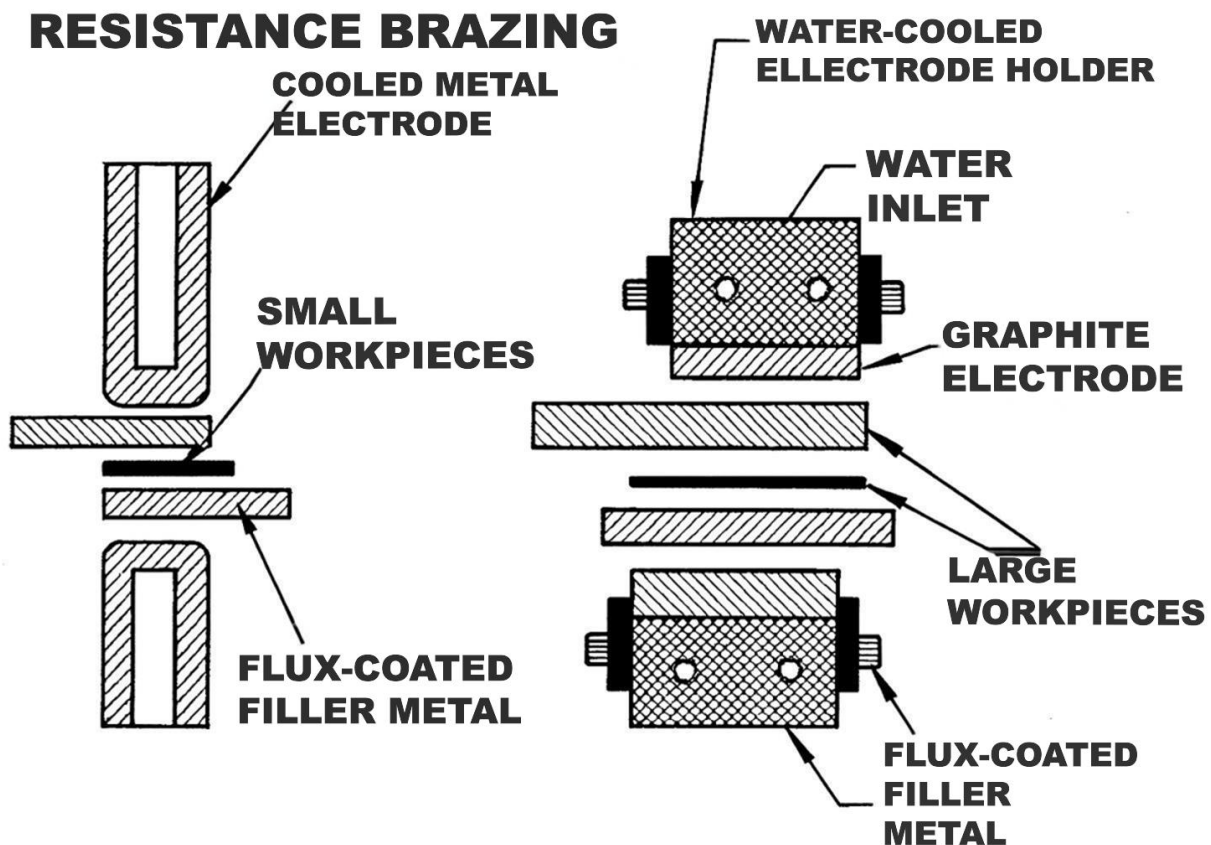


Figure 5 Resistance Brazing process description [1]

1.3.2 Application

Resistance brazing is widely utilized across various industrial sectors where precise and localized heating, along with rapid joining, are essential requirements. The process is particularly well-suited for assembling small to medium-sized components, including electrical contacts, connectors, wire terminations, and certain types of heat exchangers. Industries such as automotive, electronics, and appliance manufacturing frequently employ resistance brazing due to the need for reliable and repeatable joints, especially in assemblies that can be easily clamped and subjected to controlled electrical current and pressure.

This technique offers distinct advantages when joining dissimilar metals, providing clean and strong joints while minimizing thermal distortion. It is especially beneficial for delicate or thin-walled parts, where excessive heat input could compromise component integrity. Resistance brazing's compatibility with automation and production line integration further enhances its appeal for high-volume manufacturing environments, supporting efficient and consistent output. Additionally, the process is suitable for repair and modification tasks, as the localized nature of the heat input helps prevent damage to surrounding areas of the assembly.

Optimal applications for resistance brazing involve joints of limited area and relatively simple geometry, which allow electrodes ready access to the assembly. The process excels in repetitive

brazing of flat, symmetrical components, and can be performed using both manual and automated methods. The temperatures achieved during resistance brazing depend on the mode employed: indirect heating is typically restricted to temperatures below 800 °C to avoid excessive burning and wastage of graphite electrodes, whereas direct heating does not face these limitations.

Special consideration is required when using flux in resistance brazing applications, due to its non-conductive properties and the associated risk of explosion. As a result, self-fluxing brazing filler materials are preferred, or in some cases, a localized protective atmosphere may be used. When flux use cannot be avoided, only a small quantity of thin paste or liquid flux is recommended to mitigate risks and maintain process efficiency.

1.3.3 Advantages and Limitations

Resistance brazing provides several significant advantages for industrial applications. One of its primary strengths is the ability to achieve rapid, localized heating directly at the joint area. This focused heating minimizes the size of the heat-affected zone and reduces the risk of distortion or warping in components that are sensitive to temperature changes. The process is highly controllable, as both the temperature and the applied pressure can be precisely regulated. This level of control supports the formation of consistent, high-quality joints, making the technique suitable for repetitive production tasks where reliability is essential.

Additionally, because the heat is generated internally within the joint through electrical resistance, resistance brazing often demonstrates superior energy efficiency compared to methods that rely on broader or less targeted heating. The process is generally clean, producing minimal oxidation and reducing the need for extensive post-braze cleaning. Its compatibility with automated manufacturing systems further enhances productivity and repeatability, making it well-suited to high-volume production environments.

Despite these advantages, resistance brazing also presents several limitations. The process requires specialized equipment, including water-cooled electrodes and high-capacity transformers, which can result in significant initial capital investment. Although running costs are generally lower than those associated with manual torch brazing, the startup expenses can be prohibitive for some applications.

Resistance brazing is most effective for joints with limited area and simple geometry. Applying both current and mechanical pressure becomes increasingly complex as joint size and assembly intricacy grow, limiting the technique's applicability to larger or more complicated parts. Furthermore, energy requirements escalate rapidly with the size of the joint, effectively restricting the process to smaller assemblies.

Another drawback is the high wear rate of graphite electrodes, particularly during indirect heating. The use of flux introduces further challenges, as it can negatively impact process repeatability. Clean contact surfaces are essential—any contamination can impede current flow and compromise the integrity of the joint. Selecting a suitable flux can also be difficult, and the process is generally not appropriate for parent materials with high melting temperatures. Lastly, due to the time required

for setup and the cost of equipment, resistance brazing may not be economical for low-volume production runs.

1.4 Furnace Brazing

Furnace brazing is a process that offers significant flexibility and control for joining components, particularly when high quality and consistency are required. There are two primary variants of furnace brazing: brazing in a protective atmosphere and vacuum furnace brazing. Protective atmosphere brazing can be performed in either continuous or batch-operated furnaces, while vacuum furnace brazing is generally limited to batch operations. Both variants share certain fundamental characteristics, which are discussed below, before detailing the individual processes.

1.4.1 General Considerations for All Furnace Brazing Processes

Within a furnace brazing operation, either many small components or a single large component can be placed inside the available furnace space. Unlike some other brazing techniques, the components are inaccessible during the brazing process. Therefore, careful preparation is essential prior to loading, including thorough jiggging if the components are not self-aligning, and ensuring that the brazing filler material and, if necessary, flux are properly positioned before heating begins. The joint design should facilitate correct placement and retention of the filler material during melting.

Process variables such as heating and cooling rates, intermediate dwell periods, peak temperatures, and times at temperature should be established through preliminary trials and recorded in procedural documentation. Since furnace brazing typically involves longer cycle times than most other brazing methods, it is important to consider the potential effects of the thermal cycle on the properties of the base materials.

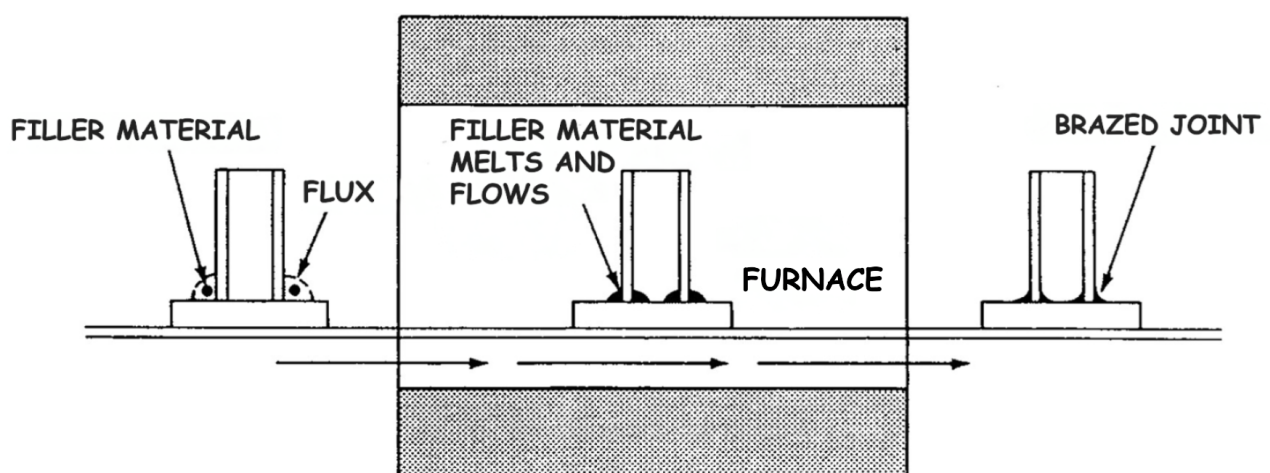


Figure 6 Furnace Brazing process description [1]

1.4.1.1 Brazing Furnaces: Types and Heating Methods

Several furnace types are utilized in industrial brazing, each tailored for specific production needs:

- 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.

Heating methods include resistance heating, gas or liquid fuel, and—increasingly—induction heating. If flame heating is used, it must not directly contact the parts to avoid localized overheating. Precise temperature control is essential, typically maintained within $\pm 6^{\circ}\text{C}$, to ensure uniform heating and minimize distortion.

1.4.1.2 Atmospheres and Fluxes in Furnace Brazing

The atmosphere within the furnace plays a critical role in determining the overall quality and reliability of brazed joints. In furnace brazing, the choice of atmosphere directly influences oxidation, contamination, and the necessity for flux. Using a vacuum or inert gas environment—such as argon or nitrogen—creates conditions where oxidation is virtually eliminated. This means that the surfaces of both the base metal and the filler metal remain exceptionally clean throughout the brazing process, which is crucial for achieving strong, high-integrity joints. In these controlled atmospheres, flux is generally not required because the absence of reactive gases prevents the formation of oxides that would otherwise impede the flow of the filler metal and weaken the joint.

However, when brazing is performed in air or partially inert atmospheres, oxidation can still occur, and flux becomes necessary to protect the joint surfaces and facilitate the flow of the filler metal. The flux can be applied in several forms, including dry powder or paste, depending on the specific requirements of the assembly and the furnace setup. For assemblies where water-based fluxes are used, it is important to remove any residual moisture prior to brazing. This is typically achieved by pre-drying the components at $175\text{--}200^{\circ}\text{C}$ for a period of 5–15 minutes in recirculating air ovens. This step is essential because any moisture present can lead to defects such as porosity, incomplete bonding, or contamination, ultimately compromising the mechanical properties of the joint.

Overall, the careful selection and management of both the furnace atmosphere and the flux type are essential steps in furnace brazing. These factors not only ensure the formation of clean, strong, and reliable joints but also help to prevent common problems such as oxidation, contamination, and moisture-related defects. By optimizing these parameters, manufacturers can consistently achieve high-quality results and enhance the performance and longevity of brazed assemblies.

Advantages of Furnace Brazing

- Minimal distortion, even for complex components
- Enables simultaneous brazing of multiple components or assemblies with multiple joints

- Excellent control of process variables, making it particularly suitable for producing high-integrity components

Limitations of Furnace Brazing

- Complete through-heating of the components is unavoidable, which may not be suitable for certain applications
- Filler materials with wide melting ranges may be unsuitable if slow heating rates lead to liquation
- Potential contamination of the furnace by metallic vapors, oxides, or flux residues

1.4.1.3 Protective Atmosphere Brazing

Flux is rarely used in protective atmosphere furnace brazing because the furnace atmosphere itself is engineered to prevent oxidation. The most common atmosphere in continuous furnaces is exothermic, produced from partially combusted natural gas or propane, and is reducing in nature. Other atmospheres include cracked ammonia, mixtures of hydrogen and nitrogen, and endothermic atmospheres. The choice of protective gas, filler material, and flux, if necessary, should be made in consultation with the filler material supplier.

1.4.2 Continuous Furnace Brazing

In continuous furnace brazing, components are conveyed through a heated tunnel furnace and then into a cooling zone. The heating and cooling cycle is determined by the conveyor speed and the furnace temperature settings.

This method is widely used for a range of materials, with the primary application being the brazing of mild steel using copper filler material. It is essential that assemblies are securely held and self-locating to prevent disturbance during movement on the conveyor. Conveyor speeds are adjusted according to the mass of the components, resulting in typical process cycle times ranging from 15 minutes to 2 hours.

Advantages of Continuous Furnace Brazing

- High throughput for production operations
- Usually does not require flux, eliminating the need for post-braze cleaning
- Components do not need to be as clean as those for vacuum brazing
- Enables the use of cost-effective brazing filler materials

Limitations of Continuous Furnace Brazing

- Requires substantial capital investment, though less per unit output than vacuum furnaces
- Not practical for frequent start-stop operation

Size Limitations

The maximum size of components that can be processed is determined by the cross-sectional area of the furnace.

Safety Considerations

Fume extraction is necessary, and there is an inherent explosion risk associated with highly reducing atmospheres, particularly those containing hydrogen-rich gases.

1.4.3 Batch Furnace Brazing

Process

In batch furnace brazing, components are loaded into a heated chamber, typically within a retort that maintains the protective atmosphere. The heating cycle is controlled by adjusting the furnace temperature, and rapid cooling can usually be achieved by removing the retort from the furnace.

Applications

Batch furnace brazing is primarily used in the electronics and electrical industries.

Advantages of Batch Furnace Brazing

- Generally fluxless, with no need for post-braze cleaning
- Components do not need to be as clean as those for vacuum brazing
- Capable of processing larger components than continuous furnaces

Limitations of Batch Furnace Brazing

- Longer process cycle times
- Retort life is limited at higher operating temperatures
- High energy consumption

Size Limitations

Large components can be processed using batch furnaces.

Safety Considerations

As with continuous furnaces, fume extraction is essential and there is an explosion risk when using highly reducing atmospheres.

1.4.4 Vacuum Brazing

Process

Vacuum brazing is performed in a furnace equipped with a water-cooled chamber and a sealable door, containing heat shields on the inner surfaces. The furnace is heated by resistance heaters attached to these shields. During heating, the furnace is continually evacuated to pressures typically between 1×10^{-3} mbar and 1×10^{-5} mbar, removing any evolved gases. Other pressure ranges may be used for specific purposes. The vacuum preserves the cleanliness of component surfaces and facilitates the flow of filler material. Both low leakage rates and sufficient pumping speed are essential. The temperature, as well as heating and cooling rates, can be precisely controlled. To accelerate cooling after brazing, cooled inert gas can be circulated within the furnace.

Applications

Vacuum brazing is particularly suitable for joining high-temperature corrosion-resistant and heat-resistant alloys, including high-alloy steels, nickel alloys (containing titanium and aluminum), and

reactive metals. The process involves slow heating, resulting in total processing times from 2 to 10 hours.

Advantages of Vacuum Brazing

- Enables brazing of high-alloy steels, nickel alloys with titanium and aluminum, and reactive metals
- Flux-free operation, eliminating the need for post-braze cleaning
- Highly precise control of heating cycles and temperatures
- Allows for combined brazing and heat treatment of the parent materials

Limitations of Vacuum Brazing

- High initial capital investment
- Requires extremely clean component surfaces—more critical than with other brazing processes
- Heating and cooling rates may not be optimal for all materials
- Volatile metals must be excluded from the furnace charge, except when brazing aluminum

Size Limitations

Production furnaces typically accommodate components with ruling dimensions from 300 mm to 1,000 mm, though larger furnaces are available for special applications.

Safety Considerations

Vacuum brazing generally presents few hazards, except for potential risks from residual backfill gases in larger furnaces. Adequate ventilation should always be ensured.

1.5 Immersion Brazing

Immersion brazing is a process in which an assembly is brought to the brazing temperature through partial or full immersion in a molten heat transfer medium. There are three main types of immersion brazing processes:

- Flux bath brazing
- Dip bath brazing
- Salt bath brazing

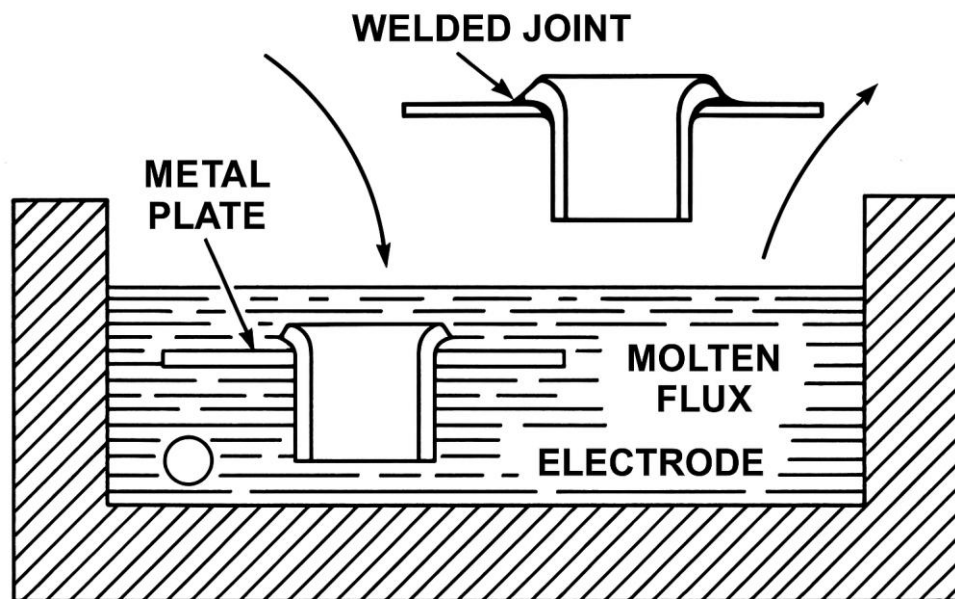


Figure 7 Immersion brazing process description [1]

1.5.1 Flux Bath Brazing

Flux bath brazing, also referred to as flux dip brazing, is the most commonly used immersion brazing technique. It involves submerging components in a bath of active molten flux. Before immersion, filler material preforms are positioned near the joint area.

Applications

This method is primarily used for brazing aluminum and certain aluminum alloys within a relatively narrow temperature range, typically around 600 °C. Flux bath brazing is particularly effective for simultaneously brazing multiple joints in complex assemblies, such as heat exchangers.

Advantages:

- Provides precise and even heating of complex assemblies
- Allows for simultaneous heat treatment

Limitations:

- Requires careful preheating of components
- 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

Size Limitations

Flux bath brazing can accommodate a wide range of component sizes, including thin sections. The maximum size is determined by the flux bath dimensions, and components up to approximately 1 meter can typically be handled.

1.5.2 Dip Bath Brazing

Process Description

Dip bath brazing involves immersing the immediate joint area in a bath of molten filler material, which is usually covered by a layer of molten flux. This method is mostly used for joining the ends of light section assemblies with limited heat capacity.

Applications

Filler materials with melting temperatures above 900 °C are rarely used; operating temperatures generally remain below 750 °C because flux stability decreases at higher temperatures. Dip bath brazing is suitable for wire terminations and junctions with appropriate geometry, offering rapid and reliable joint formation.

Advantages and Limitations

Advantages:

- Accommodates wide brazing gaps
- Produces high-quality joints
- Enables rapid heat transfer

Limitations:

- Bath composition may drift and requires monitoring
- Flux must be replenished frequently
- Components need to be preheated
- Component surfaces are coated with filler material, which can be wasteful

Size Limitations

Dip bath brazing is generally used for components up to 5 mm in cross section and only a few centimeters in length. Larger parts are impractical due to the chilling effect of greater mass.

1.5.3 Salt Bath Brazing

Process Description

Salt bath brazing, now largely obsolete, involves submerging the assembly in a fused salt bath. Prior to immersion, a brazing filler material preform and suitable flux are applied to the joint area.

Applications

This technique is mainly used for ferrous components, often combining brazing and heat treatment in a single operation. Only EN 1044, AG, and CU3XX filler materials with melting temperatures above 750 °C are suitable for this process.

Advantages:

- Ensures uniform temperatures and rapid heating
- Keeps components free from scale
- Allows for combined heat treatment and brazing

Limitations:

- Requires preheating to dry the flux
- Not suitable for light section parts due to floatation and surface tension effects of the salt
- Salt removal and safe disposal can be problematic

Size Limitations

Salt bath brazing is impractical for small, low-mass parts. The maximum size of components is determined by the available bath size.

1.6 Special Processes

1.6.1 Laser Beam Brazing

Laser beam brazing is a joining process that utilizes a high-energy laser beam as a localized heat source to melt a filler metal whose melting temperature is lower than that of the parent materials. The laser's highly concentrated and precisely controllable heat allows for exact energy input and minimizes the thermal effect on surrounding material. Typically, a continuous wave laser beam is used, which can be defocused to heat the pre-placed or automatically fed brazing filler material to its melting temperature. Simultaneously, the joint surfaces of the components are heated to a temperature sufficient for localized wetting and flow of the filler material. The laser beam is absorbed only at the top surface of the joint. Key process variables include laser power, beam focusing, travel speed, and details of wire supply and shielding gas composition.

1.6.1.1 Applications

Laser brazing is particularly suitable for components that require minimal or highly localized heat input to the joint. Its ability to deliver high-quality joints with low overall heat input and excellent dimensional control makes it ideal for thin sheets, visible joints, and components where distortion, residual stresses, or surface appearance are critical. The process is widely used in automotive body manufacturing, consumer products, and precision assemblies, especially where smooth and aesthetically pleasing seams are desired. It is also well-suited for automated and robotic production environments, thanks to the non-contact nature of the laser, which ensures high repeatability and easy integration into production lines.

1.6.1.2 Filler Materials and Joint Preparation

The process commonly employs copper-based filler metals due to their good wetting properties and corrosion resistance. Proper joint preparation is essential, as laser brazing relies on clean, well-defined joint surfaces to ensure consistent wetting and bonding. Surface contamination, incorrect joint gaps, or improper filler positioning can significantly impact joint quality. The process offers limited tolerance for variation compared to conventional thermal brazing methods, necessitating careful setup and monitoring.

1.6.1.3 Process Control and Parameters

Control of the laser brazing process is critical. Essential parameters include laser power, beam focus position, travel speed, filler wire feed rate, and shielding gas composition. Excessive laser power can partially melt the base material, turning the process into a fusion weld, while insufficient energy may result in inadequate wetting or incomplete bonding. The narrow processing window requires careful management to achieve stable and repeatable results. The process demands a high level of technical expertise from operators and engineers, as well as well-maintained equipment and precise alignment.

1.6.1.4 Advantages and Limitations

Laser brazing offers several advantages, such as a localized heat source and suitability for sealing joints where uniform heating of the entire joint is impractical. Its main limitations include suitability only for thin sheets, high capital costs, and limited capillary flow. For certain metals, such as copper, beam reflection can cause operational difficulties. Additionally, the process is not practical for applications requiring frequent switching on and off of the laser.

1.7 Braze welding with arc

Arc braze welding is a metal joining technique that combines elements of both fusion welding and traditional brazing. Unlike standard welding methods, in which the parent materials are melted together, arc braze welding utilizes an electric arc to provide the necessary heat to melt a filler metal. This filler metal, which has a lower melting point than the base materials, becomes molten and flows over the heated surfaces without melting the parent metals themselves. The resulting joint is formed primarily through metallurgical bonding and diffusion, rather than by fusion of the base materials. This approach helps to minimize the thermal impact on the workpieces while benefiting from the precise control that arc-based processes offer.

1.7.1 MIG (Metal Inert Gas) Brazing

One of the most prominent and widely adopted forms of arc braze welding is MIG brazing. In this process, a consumable wire electrode—commonly composed of copper or a copper alloy—is continuously fed through a MIG torch. The electric arc generated by the torch selectively heats the joint area, causing the filler wire to melt and be deposited onto the surfaces to be joined. Notably, the base materials remain solid, which is especially advantageous when working with coated steels such as galvanized or aluminized sheet. MIG brazing reduces damage to protective coatings and minimizes the risk of zinc evaporation, porosity, and distortion, all of which are concerns in conventional arc welding methods.

During MIG–Brazing, copper or copper-silicon (CuSi 3) wires are typically used as fillers. The process ensures that the galvanization layer is largely preserved, as the base metal does not reach its melting temperature. This is a key benefit in applications requiring corrosion resistance and a good surface finish.

1.7.2 Process Overview

Arc brazing and braze welding processes are generally divided into two categories: gas-shielded metal arc (MIG) brazing/braze welding and tungsten inert gas (TIG) brazing/braze welding. The basic principle is similar to that of MIG or plasma arc welding using wire consumables. Copper alloy filler materials are commonly employed, owing to their suitable melting temperatures and corrosion resistance.

1.7.3 Applications

This method is particularly well-suited for joining surface-coated or uncoated thin sheet metals, such as galvanized sheets. Its ability to maintain the integrity of surface coatings and provide a high-quality joint makes it valuable in industries that require dimensional precision and corrosion resistance, such as automotive manufacturing and thin-sheet metal fabrication.

1.7.4 Advantages and Limitations

1.7.4.1 Advantages

Arc braze welding offers several key advantages. First, it significantly reduces damage to surface coatings and applies a lower thermal load to the workpiece, primarily because the filler materials used have a lower melting temperature than the base materials. This is especially important for maintaining protective coatings and minimizing unwanted thermal effects. Additionally, the filler materials employed in this process are largely corrosion resistant, which serves to enhance the overall durability of the welded joints. Minimal melting of the parent materials occurs during the process, which helps to preserve dimensional accuracy and prevents distortion of the components being joined. Furthermore, arc braze welding operates under localized shielding gas atmospheres, eliminating the need for fluxes and simplifying the process.

1.7.4.2 Limitations

Despite its advantages, arc braze welding does have certain limitations. The joint area must be accessible for the shielded gas torch or plasma gas torch, which can restrict the technique's versatility in some applications. Additionally, the process is typically best suited for sheet thicknesses up to 3 mm, limiting its use for thicker materials.

1.8 Infra-red brazing

Recent advancements in high-intensity quartz lamps, which can reach outputs of up to 5,000 W (although welding is possible with lower power), have made it feasible to use infrared radiation as a heat source for welding processes. The thermal energy delivered to the workpiece decreases with the square of the distance from the lamp. Because these lamps emit radiation over a wide angle, concentrators are used to focus the infrared energy on specific areas where welding is needed.

Infrared Brazing refers to a metal-joining technique that utilizes infrared (IR) radiation for heating. In contrast to traditional methods, infrared brazing achieves heating without direct contact, allowing for precise and uniform temperature control. IR energy is absorbed by the surfaces of the components, quickly bringing them to the temperature required to melt the filler metal.

When the filler material becomes molten, it is drawn into the joint through capillary action, creating a strong and enduring bond between the parts. The fast and localized heating enabled by infrared brazing helps minimize both thermal stress and oxidation, which is especially beneficial for working with fragile or thin materials.

Infrared brazing is widely used in industries such as electronics, automotive, and aerospace. It is particularly well-suited for joining metals like copper, stainless steel, and aluminum, offering a clean, efficient, and highly controlled solution ideal for manufacturing intricate assemblies.

1.9 Electron Beam brazing

Electron beam brazing is a brazing process in which heat is generated by a focused beam of high-velocity electrons impacting the joint area. The kinetic energy of the electrons is converted into heat upon contact with the workpiece, allowing very precise and localized melting of the filler metal while keeping the thermal effect on the parent materials extremely low. The process is normally carried out under vacuum conditions, which ensures a clean joining environment and prevents oxidation during brazing.

A major characteristic of electron beam brazing is the exceptional level of control over heat input and penetration depth. The beam can be finely adjusted in terms of power, focus, and travel speed, enabling the joining of delicate or highly sensitive components with minimal distortion. This makes the process particularly suitable for thin sections, complex geometries, and assemblies where dimensional accuracy is critical.

The vacuum environment used in electron beam brazing provides significant metallurgical advantages. The absence of atmospheric gases eliminates the need for fluxes and reduces the risk of contamination, resulting in clean joints with consistent wetting and high repeatability. However, the requirement for vacuum chambers limits the size of components that can be processed and increases the complexity and cost of the equipment compared to other brazing methods.

Process control is essential in electron beam brazing due to the narrow operating window. Key parameters include beam current, accelerating voltage, focus position, travel speed, and filler material feed method. Small deviations in these parameters can lead to incomplete wetting, excessive heating, or unintended melting of the base material. As a result, thorough process development and validation are typically required before production use.

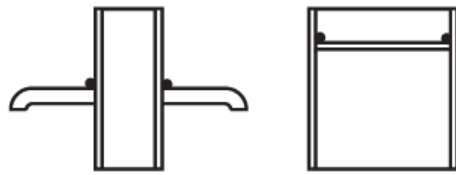
Electron beam brazing is commonly applied in high-technology sectors such as aerospace, nuclear, medical devices, and precision instrumentation, where joint cleanliness, reliability, and repeatability are of paramount importance. While the process is less flexible than arc or laser brazing in terms of setup and component size, it offers unmatched precision and joint quality when applied to suitable applications.

2 Preparation of Work Pieces for Brazing

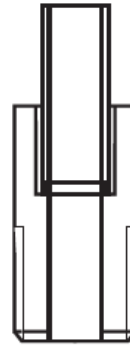
2.1 Joint Design

2.1.1 Principle

The brazing process relies on the capillary flow of a molten brazing filler material between components that are separated by a narrow gap. The filler material is designed with a different composition than the base components being joined. This difference in composition can influence the performance characteristics of the final assembly, especially in environments involving elevated temperatures, corrosive media, or repeated loading that may cause fatigue. Furthermore, the brazing cycle itself can alter the material properties of the parent components that are being joined.



Rings are suitable for a wide range of tube/plate and tube/fitting assemblies



Internal pre-placement often assists visual inspection of brazed assemblies



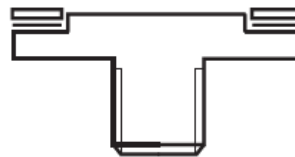
The use of loading grooves ensures that the filler material is in the correct position



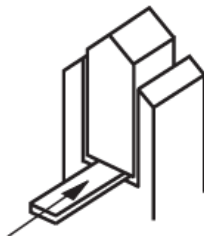
Foil is ideal for brazing corrugated or honeycomb cores to facing sheets



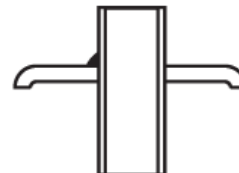
Brazing foil discs and shims are widely used for joining flat surfaces



When the filler material is pre-placed in the joint, washers may be preferred to wire rings since there is less displacement of the components



Cut lengths of wire, or strip often prove a convenient method of pre-placing filler material



Brazing pastes facilitate automatic application of filler material

Figure 8 Pre-placement of filler material

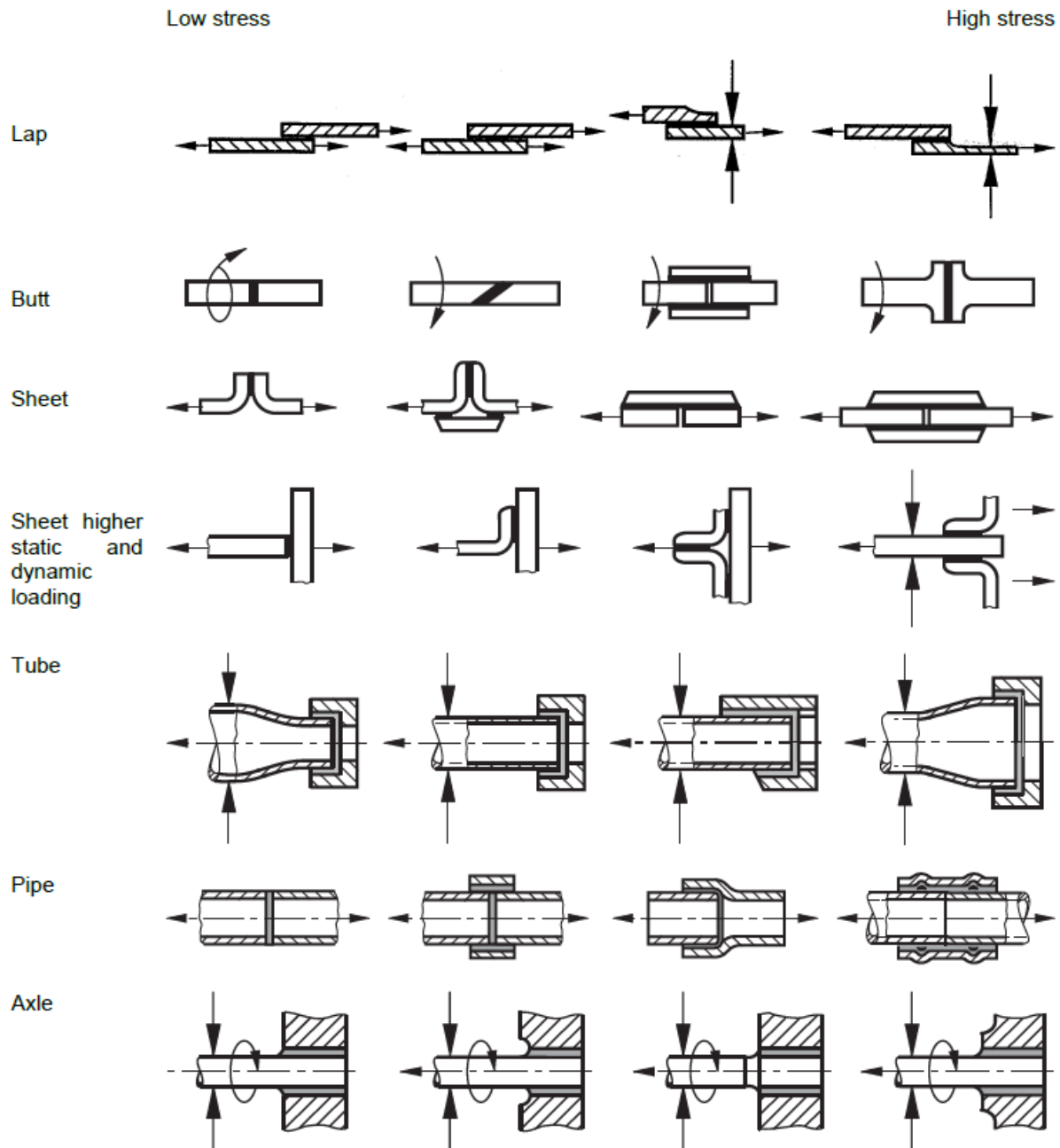


Figure 9 Design Modifications to deal with high service stresses [2]

2.1.2 Types of Joints

There are essentially two fundamental types of joints used in brazing. While these basic configurations serve as the foundation, actual assemblies are often more complex than the simple examples shown in Figure 7.

Lap joints are commonly selected because they are easier to fabricate and typically provide greater strength. In contrast, butt joints are chosen when sufficient strength can be achieved, such as in cases where the mechanical properties of the parent materials are lower than those of the brazed

joint, or when the physical dimensions of a lap joint—such as its thickness or length—are impractical or undesirable.

It is important to recognize that, for lap joints in shear, the effective overlap length is related to the thickness of the thinner component. Increasing the overlap length beyond the optimum provides minimal improvement in joint strength.

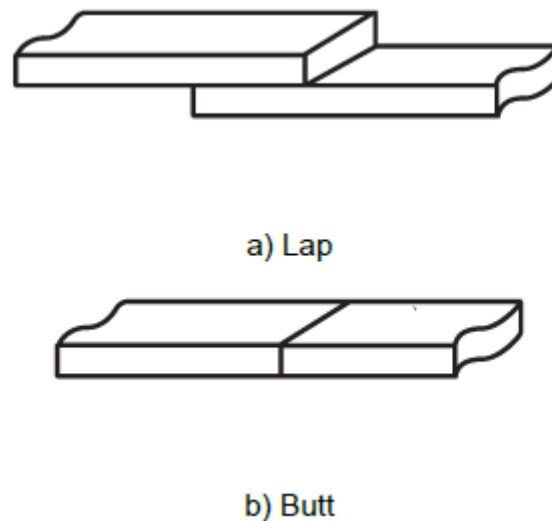


Figure 10 Lap and Butt joints

2.2 Assembly Gap and Brazing Gap

The different areas of a brazed assembly are illustrated schematically in Figure 3. One of the most critical aspects of brazing is the precise control of the brazing gap—the gap present at the brazing temperature between the components to be joined, which the filler material must penetrate via capillary action. Several factors play a role in determining the ideal brazing gap, all of which must be carefully considered during assembly.

It is important to recognize that when joints are made between dissimilar parent materials, the assembly gap (the fit-up before brazing) often needs to differ from the brazing gap. The assembly gap may need to be either larger or smaller than the brazing gap, depending on the thermal expansion coefficients of the materials involved, the specific configuration of the assembly, and the brazing process used.

Different filler materials may require different gap sizes, even within the same filler material group, as demonstrated by the typical ranges presented in Table 1. However, the optimum gap can also be influenced by several other joint parameters, including:

- The type of parent material or materials being joined
- The geometry of the joint

- The surface finish of the faying surfaces
- The use of flux or a protective atmosphere during brazing
- Careful control of both the brazing temperature and the heating rate
- The specific brazing process employed

Table 1 Influence of filler material placement and/or joint design on flow [2]

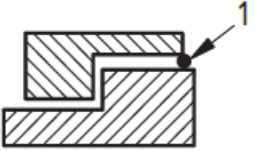
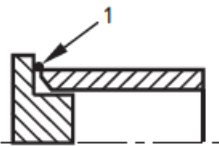
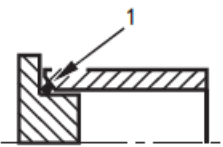
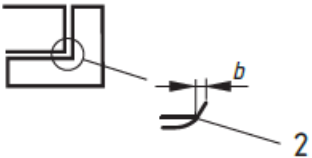
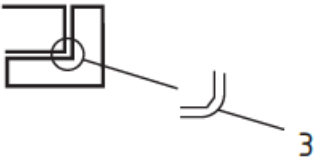
No.	Basic design	Improved design	Comments
1			1 – Filler material Where the gap varies, the filler material should be fed from the wider end.
2			1 – Filler material
3			2 – Barrier to flow 3 – Chamfer Chamfer added to aid filler material flow. This may also be aided by positioning filler material as shown in No. 2 of this table

Table 2 Influence of filler material placement and/or joint design on flow [2]

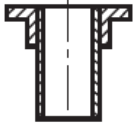
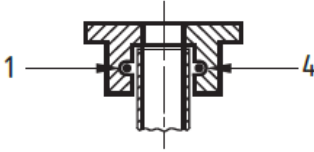
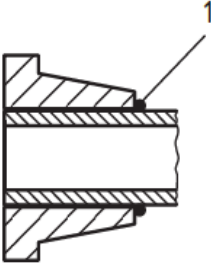
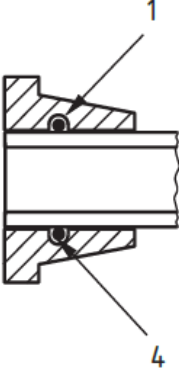
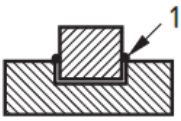
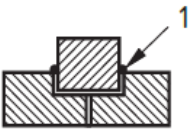
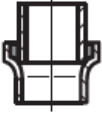
No.	Basic design	Improved design	Comments
4			4 – Filler material in loading groove If the assembly needs brazing in this position then a loading groove would be preferred as it is difficult to feed a flush joint.
5			4 – Filler material in loading groove The use of a loading groove will give a higher chance of joint soundness.
6			1 – Filler material When filler material is applied externally, the hole will permit the removal of flux residues.
7			5 – Before brazing 6 – After brazing Improved design prevents gas/flux entrapment.

Table 3 Influence of gap geometry [2]

No.	Basic design	Alternative design	Comments
1			The alternative design illustrated is more suited to capillary brazing processes. The basic design illustration is more suited to processes that are less dependent on capillary flow.
2			
3			



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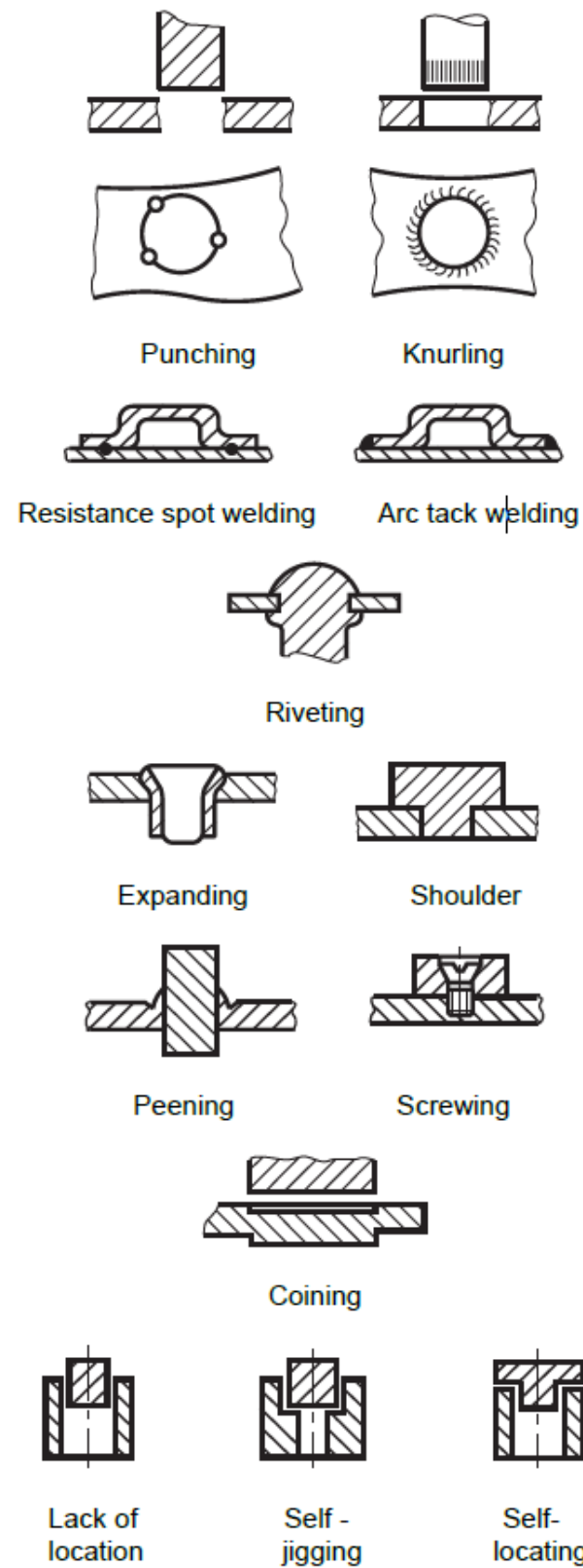


Figure 11 Common methods of locating components prior to brazing [2]

2.2.1 Influence of Brazing Filler Materials

The selection of brazing filler materials significantly affects the quality and characteristics of the resulting joint. Filler metals with a short melting range, which frequently include substantial amounts of elements that lower the melting temperature (such as silicon, boron, phosphorus, and zinc), tend to demonstrate superior fluidity. These compositions, including most eutectic alloys and many pure metals, allow for excellent capillary penetration within the joint. As a result, these types of filler metals are especially suitable for applications where narrow gaps need to be filled efficiently.

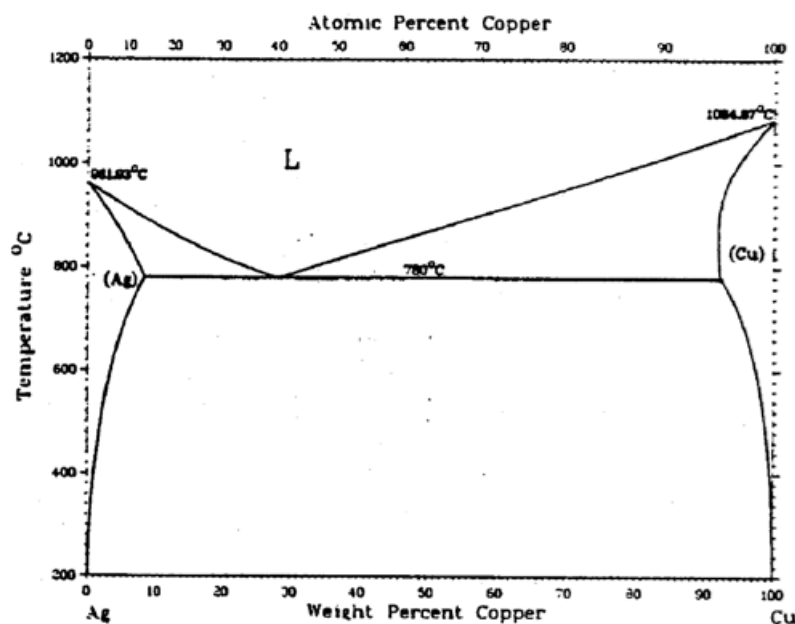


Figure 12 Cu-Ag Phase Diagram [1]

In contrast, filler materials characterized by a wider melting range are generally more effective for filling wider gaps. Their properties make them preferable for brazing operations where the joint clearance is towards the upper limit of the recommended range, as their broader melting window supports the bridging of larger spaces between components.



Table 4 Filler materials for brazing [1]

Fusion Interval	Caracteristics			Standard				
° C	R daN/mm ²	A%	d	NF	DIN	BS	AWS	EN ISO 3677
710-860	55	6	8,1		L Cu P6			B Cu 94 P 710-860
710-845	55	5	8,1		L Cu P6	CP6		B Cu 94 P 710-845
710-825	50	4	8,1	07B1				B Cu 93 P 710-825
710-815	45	4	8	07B1	L Cu P7			B Cu 93 P 710-815
710-805	45	4	8	07B1	L Cu P7	CP3	B Cu P2	B Cu 93 P 710-805
710-785	45	4	8	07B1	L Cu P7		B Cu P2	B Cu 93 P 710-785
710-750	45	3	8	08B1	L Cu P8			B Cu 92 P 710-750
710-738	40	2	8	08B1	L Cu P8			B Cu 92 P 710-738
710-840	52	5	8,1		L-Cu P6			B Cu 94 P 710-840
710-815	45	4	8	07B1	L-Cu P7			B Cu 93 P 710-815
710-790	45	4	8	07B1	L-Cu P7		B Cu P2	B Cu 93 P 710-790
710-770	45	4	8	07B1	L Cu P7		B Cu P2	B Cu 93 P 710-770
710-750	45	4	8	08B1	L-Cu P8			B Cu 92 P 710-750
710-738	40	2	8	08B1	L-Cu P8			B Cu 92 P 710-738
650-700	35	2	8					B Cu 86 Sn P 650-700
710-815	50	5	8,1					B Cu93PAg 710-815
650-825	55	6	8,1					B Cu93PAg 650-825
650-820	55	6	8,1	07B2				B Cu93PAg 650-820
650-820	55	6	8,1	06B1	LAg2P	CP2		B Cu91PAg 650-820
650-800	55	6	8,1				BCuP6	B Cu91PAg 650-800
650-810	65	8	8,2	06B2	L Ag5P	CP4	BCuP3	B Cu89PAg 650-810
650-770	60	7	8,2				BCuP7	B Cu88PAg 650-770
650-750	65	8	8,3					B Cu84AgP 650-750
650-800	70	10	8,4	05B1	L Ag15P	CP1	BCuP5	B Cu80AgP 650-800
650-720	45	4	8,2	07B3			*BCuP4	B Cu87PAg 650-720

Table 5 Filler materials for brazing [1]

Clasification	Solidus		Liquidus		Range	
AWS	°F	°C	°F	°C	°F	°C
Ag						
BAg-1	1125	607	1145	618	1145-1400	618-760
BAg-1 a	1160	627	1175	635	1175-1400	635-760
BAg-2	1125	607	1295	702	1295-1550	702-843
BAg-2 a	1125	607	1310	710	1310-1550	710-843
BAg-3	1170	632	1270	688	1270-1500	688-816
BAg-4	1240	671	1435	779	1435-1650	779-899
BAg-5	1250	677	1370	743	1370-1550	743-843
BAg-6	1270	688	1425	774	1425-1600	774-871
BAg-7	1145	618	1205	652	1205-1400	652-760
BAg-8	1435	779	1435	779	1435-1650	779-899
BAg-8 a	1410	766	1410	766	1410-1600	766-871
BAg-1 3	1325	718	1575	857	1575-1775	857-968
BAg-1 3 a	1420	771	1640	893	1600-1800	871-982
BAg-1 8	1115	602	1325	718	1325-1550	718-843
BAg-1 9	1435	779	1635	891	1610-1800	877-982
BAg-20	1250	677	1410	766	1410-1600	766-871
BAg-21	1275	691	1475	802	1475-1650	802-899
Al-Si						
BAISi-2	1070	577	1135	613	1110-1150	599-621
BAISi-3	970	521	1085	585	1060-1120	571-604
BAISi-4	1070	577	1080	582	1080-1120	582-604
BAISi-5	1070	577	1095	591	1090-1120	588-604
BAISi-6b	1038	559	1125	607	1110-1150	599-621
BAISi-7b	1038	559	1105	591	1090-1120	588-604
BAISi-8b	1038	559	1075	579	1080-1120	582-604
Au						
BAu-1	1815	991	1860	1016	1860-2000	1016-1093
BAu-2	1635	891	1635	891	1635-1850	891-1010
BAu-3	1785	974	1885	1029	1885-1995	1029-1091
BAu-4	1740	949	1740	949	1740-1840	949-1004
BAu-5	2075	1135	2130	1166	2130-2250	1166-1232

Table 6 Filler materials for brazing [1]

Clasification	Solidus		Liquidus		Range of brazing temperatures	
AWS	°F	°C	°F	°C	°F	°C
Cu and Cu-Zn						
BCu-1	1980	1082	1980	1082	2000-2100	1093-1149
BCu-1 a	1980	1082	1980	1082	2000-2100	1093-1149
BCu-2	1980	1082	1980	1082	2000-2100	1093-1149
RBCuZn-A	1630	888	1650	899	1670-1750	910-954
RBCuZn-C	1590	866	1630	888	1670-1750	910-954
RBCuZn-D	1690	921	1715	935	1720-1800	938-982
Cu-P						
BCuP-1	1310	710	1695	924	1450-1700	788-927
BCuP-2	1310	710	1460	793	1350-1550	732-843
BCuP-3	1190	643	1495	813	1325-1500	718-816
BCuP-4	1190	643	1325	718	1275-1450	691-788
BCuP-5	1190	643	1475	802	1300-1500	704-816
BCuP-6	1190	643	1450	788	1350-1500	732-816
BCuP-7	1190	643	1420	771	1300-1500	704-816
Mg						
BMg-1	830	443	1110	599	1120-1160	604-627
BMg-2 a	770	410	1050	566	1080-1130	582-610
Ni						
BNi-1	1790	977	1900	1038	1950-2200	1066-1204
BNi-1 a	1790	977	1970	1077	1970-2200	1077-1204
BNi-2	1780	971	1830	999	1850-2150	1010-1177
BNi-3	1800	982	1900	1038	1850-2150	1010-1177
BNi-4	1800	982	1950	1066	1850-2150	1010-1177
BNi-5	1975	1079	2075	1135	2100-2200	1149-1204
BNi-6	1610	877	1610	877	1700-2000	927-1093
BNi-7	1630	888	1630	888	1700-2000	927-1093
BNi-8	1800	982	1850	1010	1850-2000	1010-1093
Co						
BCo-1	2050	1121	2100	1149	210-2250	1149-1232

2.2.2 Influence of Parent Material

The nature of the parent materials being joined also plays a critical role in determining the optimal brazing gap. For parent materials that do not readily dissolve into the brazing filler or do not interact to form alloy layers, the joint gaps can typically be made tighter. This allows the filler metal to flow and penetrate more easily without being impeded by significant alloy formation at the interface.

However, when there is substantial inter-alloying between the filler and the parent materials, the fluidity of the filler can be reduced. In such cases, it becomes necessary to increase the brazing gap to ensure that the filler material can fully penetrate and fill the joint. Therefore, the extent of alloying interaction directly influences the required gap size for effective brazing.

2.2.3 Influence of Dissimilar Parent Materials

When brazing dissimilar parent materials with differing coefficients of thermal expansion, special attention must be given to the joint design to achieve the correct gap at the brazing temperature. If not properly accounted for, the gap may close entirely or open excessively during heating, which can lead to inadequate penetration or retention of the filler metal within the joint.

To address this, the assembly determined during the machining of the components, must be calculated based on the thermal expansion coefficients of the parent materials, the dimensions of the components, and the intended brazing temperature. This consideration is increasingly important as the size of the assembly grows, the brazing temperature rises, or the difference in thermal expansion between the materials becomes larger. Proper calculation and joint design are essential to ensure the reliability and integrity of brazed joints involving dissimilar materials.

2.3 Surface preparation

2.3.1 Wettability

Wettability refers to the ability of a molten filler metal to spread across and adhere to the surface of a base material, which is a critical factor in producing strong and durable brazed joints. This property is largely determined by surface tension forces that exist at the interface between the liquid filler metal and the solid base metal. When wettability is high, the filler metal is able to flow evenly into the joint, encouraging the formation of strong metallurgical bonds and minimizing the occurrence of voids or other defects within the joint.

2.3.1.1 Assessment of Wettability

To evaluate wettability, two principal experimental methods are commonly employed: the meniscodiagram and the variable clearance test. The meniscodiagram involves examining the shape and height of the molten metal's meniscus that forms between two surfaces. This observation provides information about the spreading characteristics and the contact angle of the filler metal. In contrast, the variable clearance test measures how well the molten filler metal can penetrate gaps of varying widths between base materials, which helps determine the optimal joint clearance necessary for achieving maximum capillary action.

2.3.1.2 Role of Surface Tension and Flux

Surface tension plays a dual role in wettability. When the contact angle between the molten filler and the base metal is high, surface tension resists the spreading of the liquid. Conversely, when the contact angle is low, surface tension promotes wetting. For efficient wetting to occur, the surface tension of the liquid filler metal must be sufficiently low compared to its adhesion to the base metal. The use of flux is crucial in this context, as fluxes remove oxides and contaminants from the surface of the base material, thereby reducing interfacial tension and allowing the filler metal to spread more effectively. Proper selection and application of flux directly impact the quality of wetting, which in turn affects the strength and integrity of the brazed joint.

2.3.1.3 Surface Preparation for Enhanced Wettability

It is essential that the component parts of a joint are clean and fit together correctly. Depending on the brazing method used, oxide layers, grease, and oil should be removed by chemical, thermal, or mechanical means, such as degreasing, pickling, or scratch brushing. Notably, the surfaces within the brazed joint should not be polished; a roughened surface can actually help the filler material flow, especially in the direction of machining marks. If necessary, surface modification techniques such as knurling may be used to improve the fit-up. For materials like nickel alloys containing titanium and aluminum, or ceramics, enhancing wettability may require covering the surfaces with a suitable material, for example by plating or metallizing.

2.3.2 Capillary Action

Capillary action is a critical phenomenon in brazing, referring to the spontaneous movement of molten filler metal into the narrow gap between closely fitted base materials. This movement is driven by surface tension forces and adhesive interactions at the interfaces, enabling the filler metal to be drawn into the joint even when working against gravity. As a result, capillary action ensures complete filling and uniform distribution of the filler metal throughout the joint, which is essential for creating strong and reliable connections.

2.3.2.1 Physical Basis of Capillary Action

The underlying principles of capillary action in brazing are described by Jurin's law. According to this law, the height to which a liquid will rise or fall in a capillary tube is inversely proportional to the tube's radius and directly proportional to the liquid's surface tension and the cosine of the contact angle. In the context of brazing, the gap between the base metals functions as the capillary tube. A narrow and uniform clearance between the components enhances the capillary rise, allowing the molten filler metal to penetrate deeply and form a strong metallurgical bond.

2.3.2.2 Meniscus Formation and Wetting

The formation of a meniscus—the curved surface of the liquid at the interface between the filler metal and the base material—serves as an indicator of wetting and capillary flow. The shape of the meniscus reflects the balance between cohesive forces within the liquid and adhesive forces with

the solid surface. A concave meniscus signifies good wetting and efficient capillary action, both of which are desirable for producing high-quality brazed joints.

2.3.2.3 Ensuring Effective Capillary Action

Capillary action is fundamental to distributing the filler metal throughout the joint area, ensuring that the entire interface is metallurgically bonded and mechanically sound. The effectiveness of capillary action is influenced by the physical properties of the filler metal and the precision of the joint's geometry. To prevent the unwanted flow of filler materials outside the intended joint area, a 'stopping-off' agent may be applied. It is important to ensure that this agent does not penetrate into the capillary joint gap, as this could inhibit the desired flow and compromise the integrity of the brazed joint.

2.3.2.4 Optimal Conditions for Wettability and Capillary Action in Brazing

Achieving optimal wettability and capillary action in brazing requires careful control of several factors. The base metals must be clean and free from oxides or contaminants, as surface impurities hinder wetting and capillary flow. The application of an appropriate flux is critical to maintain a clean interface and promote the spreading of the molten filler.

Joint design should provide a consistent and narrow clearance—typically between 0.05 mm and 0.2 mm—tailored to the specific filler and base materials. Excessive clearance reduces capillary forces, while too narrow a gap may prevent adequate filler penetration. The selection of filler metal with suitable surface tension and melting characteristics is also vital.

Temperature control is another key aspect; the assembly must be heated uniformly to ensure the filler metal remains fluid and capable of wetting the surfaces and flowing by capillary action. Overheating can cause oxidation, while insufficient heating impedes flow. By optimizing these parameters—surface cleanliness, flux application, joint clearance, filler metal selection, and temperature—engineers can maximize both wettability and capillary action, resulting in strong, reliable brazed joints.

Joint design, brazing temperature, and the method of heat application must be carefully considered to ensure effective capillary action during the brazing process. When the flux is in a liquid state—either because it has been applied as such or has melted during heating—the same capillarity phenomenon occurs, aiding the distribution of the molten filler metal throughout the joint. This underscores the importance of controlling not just the materials and filler selection, but also the heating technique and flux behaviour to achieve optimal results.

When high service requirements are expected, the brazed joint should exhibit mechanical properties equal to or greater than those of the weakest material among the components being joined. The choice of joint type, together with the appropriate filler metal and brazing technique, is therefore crucial to achieving reliable, high-performance assemblies.

2.3.3 Surface Cleaning

A successful brazing operation begins with the thorough cleaning and preparation of the surfaces to be joined. It is essential to remove all oxides, grease, oil, and other contaminants from both the base material and the filler metal to achieve a sound, high-quality joint. Complete cleanliness of the surfaces is required for effective capillary action and uniform wetting, both of which are necessary to create strong and reliable brazed connections. While some fluxes exhibit cleaning properties, their primary function is to remove oxides during heating, not to eliminate general contaminants.

Cleaning should be performed immediately prior to brazing to prevent recontamination of the surfaces. Maintaining the correct joint clearance after cleaning is also critical, as it facilitates optimal capillary flow of the filler metal. Cleaning methods are generally divided into two main categories: chemical and mechanical.

2.3.3.1 Chemical Cleaning Methods

Chemical cleaning encompasses a variety of techniques and agents tailored to the specific contaminants and materials involved:

- Solvents, such as petroleum-based or chlorinated hydrocarbons
- Degreasing vapors, including stabilized trichloroethylene or perchloroethylene
- Alkaline products, which may be commercial blends of silicates, phosphates, carbonates, detergents, wetting agents, and occasionally hydroxides
- Emulsion cleaners made from hydrocarbons, fatty acids, wetting agents, and activators
- Electrolytic cleaners, both anodic and cathodic types
- Acid cleaners, typically phosphates
- Pickling acids such as sulfuric, nitric, or hydrochloric acid
- Salt bath pickling, which may be electrolytic or non-electrolytic
- Ultrasonic cleaning, using high-frequency sound waves to remove contaminants

The choice of chemical cleaning agent depends on the type of contamination present, the base metal, the condition of the surface, and the joint design. Commercially prepared cleaning products are available for different materials. After cleaning, it is crucial to remove all residues through proper rinsing, as any remaining chemicals can undermine the quality and durability of the joint.

2.3.3.2 Mechanical Cleaning Methods

Mechanical cleaning is widely used to remove impurities, especially when petroleum derivatives or oils are present from machining processes. These must be eliminated before brazing. Common mechanical cleaning techniques include:

- Grinding or using abrasive wheels
- Filing
- Blasting, which involves projecting clean particles, liquids, or gases onto the surface
- Brushing

Blasting is the most common mechanical method and can use clean iron or hardened steel shot, or stainless steel powder or grit. Certain materials should be avoided in blasting, such as spherical

metallic shot (which can scratch surfaces), non-metallic abrasives like alumina, zirconia, silica, or silicon carbide (which may embed in the surface and hinder filler flow), and any moist materials, which can introduce water or minerals that contaminate the joint. When cleaning by projection, it is important that the cleaning material itself is clean and does not leave any residue or cause damage to delicate components.

2.3.3.3 Special Considerations for Flux-Free Atmosphere Brazing

In flux-free atmosphere brazing, component cleanliness is even more critical. Cleaned parts must be preserved and protected, often by assembling them in a dedicated clean room that is physically separated from other work areas, with controlled atmosphere and cleanliness standards to prevent recontamination.

2.3.3.4 Surface Coating Prior to Brazing

In some cases, it is advantageous to coat joint surfaces with a material that possesses better weldability than the base metal. Surface coating offers two main benefits: it enables faster and more uniform brazing, and it eliminates the need for strong acid fluxes. This approach is particularly useful for base materials prone to forming stubborn oxide layers. Common coating methods include hot dipping and electrolytic immersion, both of which prepare the surfaces for optimal brazing performance.

2.3.3.5 Degree of Cleanliness Required

The required level of cleanliness depends on both the desired quality of the final component and the brazing process to be used. The strictest preparation standards are necessary for flux-free, controlled atmosphere brazing performed at higher temperatures.

2.4 Influence of Atmospheres and Fluxes on Brazing

The atmosphere or flux used during the brazing process plays a critical role in determining the quality and characteristics of the joint. When a protective atmosphere or vacuum is employed, it allows for tighter joint gaps with the selected brazing filler materials than would be possible in a comparable process using flux. If joint gaps are insufficient, flux and gas pockets may be bypassed and trapped within the finished joint, which can compromise integrity.

Controlled atmospheres serve to prevent oxidation during brazing. In many instances, they also help reduce existing oxides, ensuring that the filler metal can effectively wet and flow across clean base metals. Furnace brazing is the most common application for controlled atmospheres, although induction and resistance brazing processes also utilize them.

When base metals that are not considered noble are exposed to air, chemical reactions such as oxidation, carbide, and nitride formation can occur. These reactions intensify with increasing temperature and are generally detrimental to the quality of welded joints. The use of fluxes and controlled atmospheres is essential to prevent these reactions and facilitate the joining process.



Fluxes are referred to by several names, including deoxidizers and cleaning agents, but are commonly known simply as flux or fluxes. The primary function of flux is not to remove oxides or contaminants after the initial cleaning and preparation of surfaces; rather, its purpose is to dissolve and remove oxides as the material is heated. As the filler metal becomes molten, the flux should be displaced, ensuring a clean and strong bond between the joined materials.

3 Designation and processing of relevant parent and filler materials, fluxes/gases

3.1 Parent Materials Used in Aerospace and Defence

The variety of materials currently used in aerospace and defense is extensive, making it impractical to list every grade suitable for brazing. The following general categories are provided for guidance, though other materials not listed may also be applicable. For materials not included in these categories, consultation with the brazing filler manufacturer is recommended.

3.1.1 Material Categories

- **Aluminum and its Alloys:** Includes pure aluminum, aluminum-zinc alloys (less than 6% zinc), aluminum-manganese alloys (less than 2% manganese), aluminum-silicon alloys (less than 2% silicon), and aluminum-magnesium alloys (less than 2% magnesium).
- **Coated Materials:** Materials with electrodeposited or other types of surface coatings.
- **Cobalt and its Alloys:** Covers pure cobalt, hard facing alloys, and corrosion-resistant alloys.
- **Copper and its Alloys:** Includes unalloyed copper, phosphorus-bearing copper, silver-bearing copper, low alloyed copper alloys (such as beryllium-copper, chromium-copper), copper-zinc alloys (brasses), copper-tin alloys (tin-bronzes, phosphor-bronzes, some gunmetals), copper-tin-lead alloys (some gunmetals), copper-nickel-zinc alloys (nickel-silvers), copper-nickel alloys (cupronickel), copper-aluminum alloys (aluminum bronzes), and copper-manganese-aluminum alloys.
- **Ferrous Metals:** Includes cast iron, malleable iron, mild steel, carbon and low alloy steels, alloy steels, high speed and tool steels, stainless steels, and heat and corrosion-resistant steels.
- **Nickel and its Alloys:** Covers pure nickel, nickel-copper, nickel-iron, nickel-chromium-iron, and nickel-chromium alloys.
- **Precious Metals:** Includes gold, platinum, palladium, silver, and their alloys.
- **Refractory Metals and Alloys:** Covers titanium, zirconium, tantalum, niobium, and their respective alloys.
- **Tungsten and Molybdenum:** Includes tungsten, molybdenum, cemented carbides, silver-tungsten, and copper-tungsten composites.
- **Non-Metallic Materials:** Examples include ceramics, graphite, tungsten carbide, diamonds, cermets, glass, and sapphire.

3.1.2 Special Considerations for Brazing Parent Materials

Brazing can influence the properties of parent materials due to the effects of temperature and metallurgical interactions. The brazing of dissimilar materials may also introduce additional considerations. The following sections address key factors to consider when brazing these materials.

3.1.2.1 Dissimilar Parent Materials

Brazing offers the advantage of joining many combinations of materials. However, the brazing cycle can affect the physical and metallurgical characteristics of the materials involved. The coefficient of thermal expansion is a primary concern, as it influences the gap between components at brazing temperature compared to the assembly gap. Residual stresses resulting from differential expansion can lead to mechanical failure, distortion, or cracking. Proper joint design and selection of filler materials can help mitigate these issues. Metallurgical effects may also impact joint strength, potentially forming brittle compounds or strengthening the joint.

3.1.2.2 Effects of the Brazing Process on Parent Material Properties

Alloys reliant on work hardening may lose strength during brazing, and this cannot be recovered. Precipitation-hardenable alloys may be affected by brazing but may regain strength through appropriate heat treatment. Additionally, corrosion properties may change following the brazing process, so it is advisable to seek guidance from the parent material supplier regarding these effects.

3.1.2.3 Alloys with Tenacious Surface Oxides

Alloys with additions that form robust oxide films, such as aluminum and titanium in stainless and nickel alloys, are more challenging to braze. Special attention is required for surface preparation and the choice of flux or atmosphere, which may include special fluxes, protective atmospheres, or pre-brazing plating.

3.1.2.4 Porous Metals

Powder metallurgy components with interconnected porosity (less than about 90% theoretical density) can absorb filler materials by capillary action, making brazing difficult. Surface sealing prior to brazing is necessary for such cases.

3.1.2.5 Metals and Alloys Containing Reducible Oxides

Metals or alloys with oxide inclusions or dissolved oxygen that are easily reduced at brazing temperatures should not be brazed in reducing atmospheres. Reduction may produce steam, causing porosity and reduced ductility.

3.1.2.6 Aluminum Alloys

Aluminum and its alloys are typically brazed using Al-Si based filler materials. Magnesium present in the parent material can react with silicon in the brazing alloy, forming intermetallic compounds at the interface. If the magnesium content exceeds 2%, the resulting compound may embrittle the joint.

3.1.2.7 Lead-Bearing Copper Alloys

Lead is used in copper alloys to improve machinability but is insoluble in copper. Lead content above about 2% can interfere with brazing by forming unwettable dross at the interface or causing cracking. These effects can be reduced with adequate fluxing and uniform heating without imposed stress.

3.1.2.8 Free Machining Carbon Steels

Lead and sulfur are added to carbon steels for machinability. Lead below 0.35% does not significantly affect brazeability or joint strength, but higher levels may reduce joint strength due to interaction with the filler material. During vacuum furnace brazing, lead may volatilize from the steel's surface. Sulfur-bearing free machining carbon steels (up to 0.6% sulfur) are readily brazed, with joint strengths comparable to sulfur-free grades.

3.1.2.9 Cast Iron

Spheroidal graphite (s.g.) cast irons can be brazed using silver filler materials. Flake graphite irons are more challenging due to flakes interfering with wetting, which can be addressed by special surface treatments or using silver brazing filler with nickel.

3.1.2.10 Reactive and Refractory Metals and Their Alloys

Titanium, zirconium, niobium, and tantalum alloys are generally not brazed; specialist advice and inert atmospheres (argon or vacuum) are required, and hydrogen atmospheres must be avoided. Molybdenum and tungsten can be brazed in hydrogen or inert atmospheres, though it is preferable to keep brazing temperatures below their recrystallization points to avoid embrittlement.

3.1.2.11 Metals Prone to Cracking During Brazing

Cracking is often caused by stressing components while they are in contact with molten filler material, due to work hardening, jig restraint, or uneven heating. Cracks usually form at grain boundaries, a phenomenon known as stress cracking or liquid metal penetration. Prevention methods include using annealed materials, ensuring even heating, and designing jigs to minimize restraint.

3.1.2.12 Non-Metallic Materials

Ceramics may be brazed by metallizing the surface prior to brazing or using reactive metal filler materials. For glass materials, special glass filler materials are available.

3.2 Filler Materials Used in Aerospace and Defense

The principal filler materials addressed in this standard are those specified in EN 1044, which are categorized into various classes. While these are the primary materials considered, other commercially available filler materials may also be used if both the manufacturer and the user agree to their suitability.



It is essential that filler materials are stored and handled according to the manufacturer's recommendations to ensure their quality and performance.

Table 7 provides specific details about the filler materials most frequently used for different combinations of parent materials. In addition, Table 8 offers guidance on the suitability of various brazing filler material classes for commonly used brazing methods. This guidance is necessarily broad, and the appropriateness of any filler material and method combination should be determined on a case-by-case basis.

Table 7 Filler materials most commonly used for combinations of parent materials [2]

Parent materials	Al & Al alloys	Cu & Cu alloys	Carbon & low alloy steels Cast iron	Stainless steel	Ni & Ni alloys	Ti & Ti alloys	Refractory metals
Filler material classes in accordance with EN 1044							
Al & Al alloys	AL						
Cu & Cu alloys		AG AU CP NI CU3XX					
Carbon and low alloy steels Cast iron		AG CU3XX	AG CU CU3XX				
Stainless steel	AL	AG NI AU D	AG CU NI	AG AU CU NI			
Ni & Ni alloys		AG AU PD	AG CU NI	AG AU CU NI	AG AU CU NI PD		
Ti & Ti alloys	AL				AG	AG AL	
Refractory metals		AG PD AU					PD AU
NOTE Bold entries are those most commonly used.							



Table 8 Suitability of brazing filler material classes for the commoner brazing methods [2]

Filler material class in accordance with EN 1044	Brazing method							
	Flame	Induction	Resistance	Furnace		Immersion		Laser beam
				Protective/ reducing atmosphere	Vacuum	Flux bath	Dip bath	
AL	S	S	U	S ^a	S ^b	S	U	S
AG	S	S	S	S ^c	AG401 ^e	U	S	S
CP	S	S	S	S	U	U	U	-
CU1XX and CU2XX	U	S	S	S	S	U	U	S
CU3XX	S	S	S	U	U	U	S	S
NI & CO	U	S	U	S	S	U	U	-
PD	U	S	U	S	S ^d	U	U	-
AU	U	S	U	S	S	U	U	-
Key S Suitable U Unsuitable ^a Only with flux. ^b Not all filler metals in the class are suitable . ^c With flux in some cases. ^d Not PD202. ^e AG401 is suitable for vacuum furnace brazing.								

3.2.1 Forms of Filler Materials

Brazing filler materials are available in several forms, including rod, wire, foil, preforms, powder, paste, and clad sheet. In some instances, certain filler materials can also be applied by spraying, coating, vacuum deposition, or they may be blended from powders. The intended forms of the brazing filler material should be established during the design phase of the project.

3.2.2 Applications of Filler Materials

The selection of a filler material for brazing a specific combination of parent materials depends on numerous factors. In some circumstances, only one filler material may be appropriate, whereas in other cases, there may be several options. It is important to note that not every filler material within a class is suitable for every application.

3.2.2.1 Class AL

Filler materials in Class AL are used almost exclusively for joining pure aluminum and a limited range of aluminum alloys.



3.2.2.2 Class AG

Silver brazing filler materials (Class AG) are widely employed for brazing various materials, with the exception of aluminum, magnesium, and refractory metals and their alloys. Special grades are available for use in vacuum brazing applications.

3.2.2.3 Class CP

Class CP filler materials are primarily used for joining copper and its alloys. With the exception of CP302, these materials are self-fluxing on copper. However, when used on most copper alloys, a flux or a protective atmosphere is required. Due to the formation of brittle phases, phosphorus-bearing filler materials in this class are generally not suitable for joining steel or nickel alloys.

3.2.2.4 Class CU

Class CU filler materials are primarily utilized for brazing applications involving copper, cemented carbide, and ferrous components. Specifically, those designated as CU3XX are used with a flux for brazing these materials. In addition, variants such as CU1XX and CU2XX are suitable for brazing ferrous and other high-melting parent materials when performed in a protective atmosphere or vacuum environment.

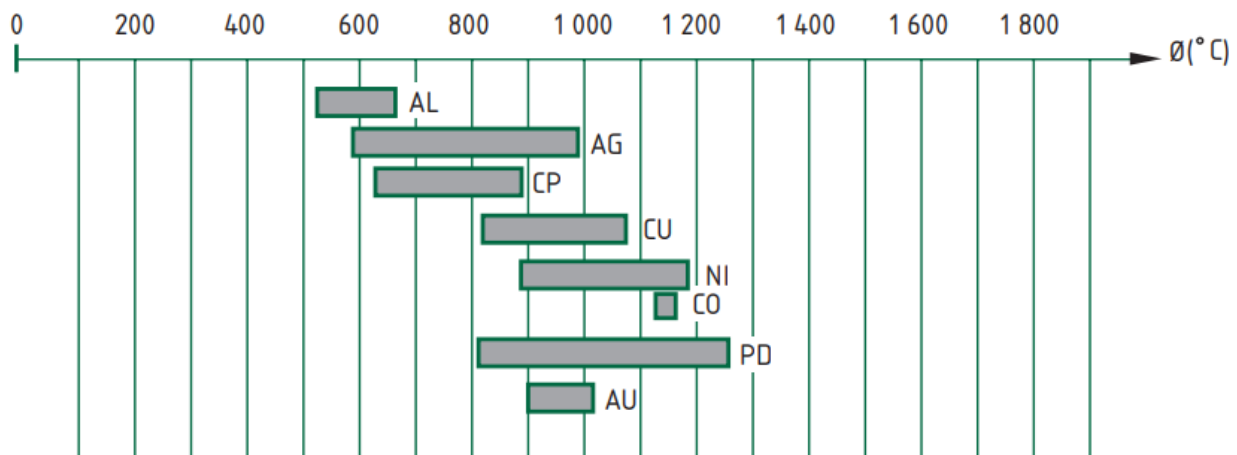
3.2.2.5 Class NI and CO

Class NI and CO filler materials are used almost exclusively for the purpose of joining stainless steel and other heat- and corrosion-resistant alloys. These filler materials are typically employed in vacuum or protective atmospheres to ensure optimal joint quality and material compatibility.

3.2.2.6 Class PD and AU

Class PD and AU filler materials find application in protective atmospheres or vacuum settings. They are used to join metallized ceramics, copper alloys, nickel alloys, and steels, providing versatility across a range of difficult-to-join materials.

EN 1044:1999 reference	Class	Composition
Table 2	AL	Aluminium brazing filler materials
Table 3	AG	Silver brazing filler materials
Table 4	CP	Copper-phosphorus brazing filler materials
Table 5	CU	Copper brazing filler materials
Table 6	NI	Nickel brazing filler materials
Table 6	CO	Cobalt brazing filler materials
Table 7	PD	Palladium bearing brazing filler materials
Table 8	AU	Gold bearing brazing filler materials
Table 1		Special 'vacuum application' versions of certain AG, PD and AU brazing filler materials



3.3 Fluxes

Fluxes play a crucial role in the brazing process, especially when brazing is performed in air. The primary exception to this requirement is the use of self-fluxing copper-phosphorus filler materials, which do not typically require additional flux. Fluxes are also fundamental to all flux bath processes, where they serve as an integral component. In certain cases, fluxes may also be utilized during brazing operations conducted in protective atmospheres.

The most frequently available forms of flux are powders and pastes, which provide versatility and ease of use. Other forms include gases, liquids, flux-coated or cored filler materials, and combinations of flux with filler materials. This diversity enables the selection of the most suitable flux type for the specific brazing application and process.

It is standard practice to apply flux prior to heating the components to be joined. The use of standardized fluxes ensures consistency and reliability in brazing outcomes. All fluxes employed for brazing must conform to the specifications outlined in EN 1045.

3.3.1 Flux Removal

It is important to recognize that some flux residues remaining after the brazing process are chemically active. To prevent undesirable corrosion of the parent material, it is essential to ensure the complete removal of these flux residues. The effectiveness of flux removal is largely determined by the degree to which the flux has been exhausted at the end of the brazing cycle. This is influenced by factors such as the application of an adequate amount of the correct flux, avoiding overheating, and minimizing heating time. If the assembly can tolerate it without sustaining damage, flux removal may be made easier by quenching the assembly in water immediately after the brazing filler material has solidified. Additionally, all flux residues should be disposed of in accordance with the relevant regulations.

3.3.1.1 Fluxes for Brazing at Temperatures ≥ 750 C (e.g., FH21, FH30)

Borax and similar high-temperature fluxes, when fused, leave residues that are hard, glassy, and relatively insoluble in water. Therefore, these residues must be removed by mechanical means, such as grit or shot blasting or other abrasive techniques.

3.3.1.2 Fluxes for Brazing at Temperatures < 750 C (e.g., FH10, FH11, FH12)

Fluoroborate fluxes used for brazing at temperatures below 750°C produce residues that are relatively soluble in water. These residues can be removed by washing in hot or boiling water. The removal process can be made more effective through agitation or the use of ultrasonic vibration. If complete removal of discoloration is necessary, chemical or proprietary inhibited descaling solutions may be employed. Non-immersion methods, such as steam lancing and wet or dry abrasive techniques, are also effective for removing these residues.

3.3.1.3 Aluminum Brazing Fluxes

Type FL10 fluxes, which are used for aluminum brazing, are highly corrosive and require thorough post-braze removal. These flux residues are water soluble and can be washed away with water. In contrast, Type FL20 fluxes are generally non-corrosive and the residues left behind can often be left in place without removal.

3.4 Atmospheres

3.4.1 Protective Atmospheres

Protective atmospheres play a crucial role in the brazing process by maintaining the cleanliness of both the parent and filler materials. This cleanliness is essential to ensure that the filler material can flow freely and create a satisfactory joint during brazing. The selection of a particular protective atmosphere depends on the properties of the parent and filler materials and may involve either active or inert gases. Table 9 provides examples of different types of protective atmospheres commonly used. It is important for users to understand that atmospheric purity, cycle time, and temperature are all interconnected variables, and any change in one can impact the requirements necessary for successful brazing.

3.4.2 Vacuum Atmospheres for Brazing

Vacuum atmospheres for brazing are established within specially designed vessels by evacuating the furnace gases, typically air, through the use of pumps. These pumps generally consist of a combination of mechanical and oil diffusion types that are carefully matched in terms of pumping capacity and are large enough to quickly evacuate the furnace space. During the heating cycle, outgassing occurs from both the components being processed and the interior surfaces of the furnace. To manage this, the pumps are often automatically interlocked with vacuum measuring instruments. This setup accommodates the changes in pressure and ensures consistent atmosphere quality.

Achieving a vacuum better than 10–3 mbar is straightforward with this equipment, but controlling the leak rate is equally important to maintain the required low levels of residual atmosphere. A



vacuum of 10–3 mbar corresponds to a gas impurity content of approximately 1.1×10^{-6} parts per million by volume, highlighting the high standard of atmospheric purity that can be achieved for effective brazing.

Table 9 Examples of protective atmospheres

No.	Source	Typical dew point of incoming gas °C	Approximate composition				Applications	
			H ₂ %	N ₂ %	CO %	CO ₂ %	Filler material class	Parent materials
1	Combusted fuel gas ^d (low hydrogen)	Up to + 30	1 to 5	87	1 to 5	11 to 12	AG ^a , CP, CU3XX ^a	Cu and some Cu alloys. Low and medium carbon steels
2	Combusted fuel gas ^d (decarburizing)	Up to + 30	14 to 15	70 to 71	9 to 10	5 to 6	AG ^a , CP, CU1XX, CU2XX, CU3XX ^a	Cu and some Cu alloys, low and medium C steel, Ni, Ni-Cu alloy
3	Combusted fuel gas ^f , dried	- 40	15 to 16	73 to 75	10 to 11	-	AG ^a , CP, CU1XX, CU2XX, CU3XX ^a	Cu and some Cu alloys, carbon steels, Ni-Cu alloy, Ni, Ni-Fe alloys
4	Combusted fuel gas ^e , dried (carburizing)	- 40	38 to 40	41 to 45	17 to 19	-	AG ^a , CP, CU1XX, CU3XX ^a	Cu and some Cu alloys, carbon steels, Ni-Cu alloy, Ni
5	Dissociated ammonia ^g (cracked ammonia)	- 54	75	25	-	-	AG, CP, CU1XX, CU2XX, CU3XX, NI106, NI107	Cu and some Cu alloys, carbon steels, Ni-Cu alloy, Ni and Ni alloys, alloys containing Cr ^b
6	Cylinder hydrogen	Down to - 60	100	^d	-	-	AG, CP, CU1XX, CU2XX, CU3XX, NI107	Cu and some Cu alloys, low and medium carbon steels, Ni and Ni alloys and alloys of Co, Cr and cemented carbides ^b
7	Inert gas ^g , e.g. argon, nitrogen ^c	Below - 60	-	-	-	-	CP, CU1XX, CU2XX, NI	Cu and some Cu alloys, carbon steels, Ni and Ni alloys ^b , alloys containing Cr
^a Flux additionally required when filler materials containing volatile elements are used. ^b Flux required in addition to atmosphere when appreciable quantities of aluminium, titanium, silicon or beryllium are present. ^c It is essential that nitrogen is not used with refractory metals or aluminium or when the filler material contains boron or silicon. ^d The combusted fuel gas (low hydrogen or decarburizing) may be referred to as exothermic. It may also be available as synthetic gas. ^e The combustable fuel gas (carburizing) may be referred to as endothermic. It may also be available as synthetic gas. ^f It may also be available as synthetic gas. ^g Certain filler materials in EN 1044:1999 Tables 7 and 8, can be brazed in protective atmospheres 5 and 7								

4 Interpretation of drawing symbols according to ISO 2553

4.1 Introduction to ISO 2553

The EN ISO 2553 standard establishes the rules for the symbolic representation of welded joints. It is essential that welded joints are clearly defined on technical drawings without any ambiguity, as aspects such as the location, type of joint, dimensions, and finish quality can significantly affect both the performance and cost of the welded construction. While the welding procedure itself is typically left to the manufacturer's discretion, these key design elements must be precisely specified during the design phase and properly reflected in the drawings.

According to ISO 2553, welds may be represented following general technical drawing conventions, although the use of standardized symbols is recommended for simplicity. All necessary details to define the joint should be included in the representation. To avoid cluttering the drawings, it is recommended that information regarding procedures, consumables, and similar details be provided in supplementary instructions rather than directly on the drawings.

The principles outlined in this document are also applicable to soldered and brazed joints. ISO 2553 recognizes two main approaches in the global market for indicating the arrow side and the other side of a joint on drawings:

- Clauses, tables, and figures marked with the suffix "A" apply only to the dual reference line symbolic system.
- Those marked with the suffix "B" apply only to the single reference line symbolic system.
- Items without either suffix are applicable to both systems.

The symbols presented in the standard can be combined with other technical drawing symbols, such as those indicating surface finish requirements. Additionally, an alternative designation method is offered, allowing essential design information—such as weld dimensions and quality level—to be specified. The production unit then determines the joint preparation and welding processes necessary to meet these requirements.

4.2 Components of a Brazing Symbol

The symbolic representation of brazed joints, as defined by ISO 2553, comprises the following essential elements:

1. **Reference line:** The central feature of the symbol, used to indicate the location and specifics of the joint on technical drawings.
2. **Basic symbols or combinations of symbols:** These denote the type of joint or weld, and may be combined to convey more complex requirements.

3. **Supplementary symbols:** Additional symbols are used to specify further characteristics, such as surface finish or quality standards.
4. **Dimensions:** The size and geometry of the weld, including length, width, and depth, are indicated to ensure accurate fabrication.
5. **Additional instructions:** Optional notes or guidance can be attached to the symbol to clarify procedures, consumables, or other relevant information.

This structured approach ensures that all necessary details are clearly and concisely presented on technical drawings, minimising ambiguity and supporting consistent interpretation across various manufacturing contexts. For greater clarity and efficiency, supplementary information such as welding procedures or material specifications should be included separately in accompanying documentation rather than directly on the drawing itself.

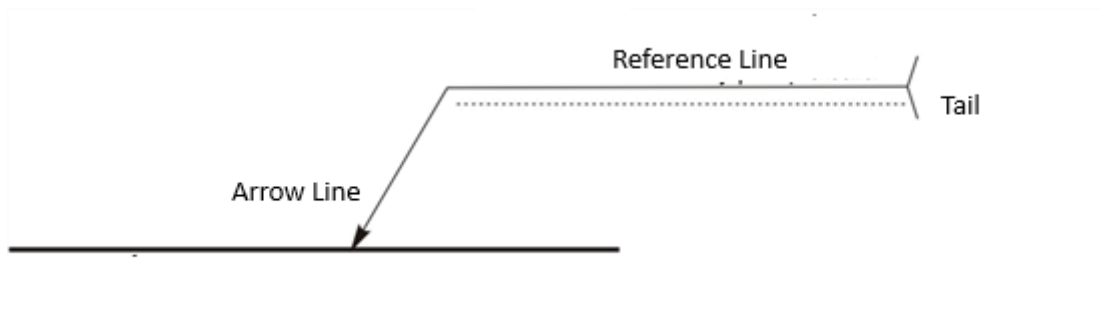


Figure 13 Reference line, Arrow Line and Tail

4.2.1 Reference Line

Indicates the location of the joint (see figure 32). It is actually composed of the following elements:

- Arrow line, which points towards the joint and shows where the welding is to be performed.
- Reference line itself, which, except for some exceptions, consists of a double line—one continuous and the other dashed—which may be placed either above or below the former. On this double reference line, the face or faces of the joint to be worked on, as well as the characteristics and dimensions of the weld to be made, are specified.
- Optional tail, where any supplementary indications may be provided.

If the intention is simply to indicate the location of a weld, without further detail, the symbol shown in the previous figure is sufficient.

In general, the position of the reference line is not significant; it only indicates where welding is required. As a result, it may be placed above, below, or to either side of the joint. Only in cases where one piece has edge preparation and the other does not, the arrow will point towards the prepared piece.

The purpose of the double reference line—one continuous and one dashed—is to specify the face or faces of the joint to be welded and the operation to be performed on each side.

In this regard, it is important to distinguish between the “arrow side”, which is the face indicated by the arrow, and the “other side”.

On the side of the continuous line, instructions for the arrow side are given; on the dashed line side, instructions for the other side. For symmetrical joints, where the same operation is carried out on both sides, the dashed line is unnecessary.

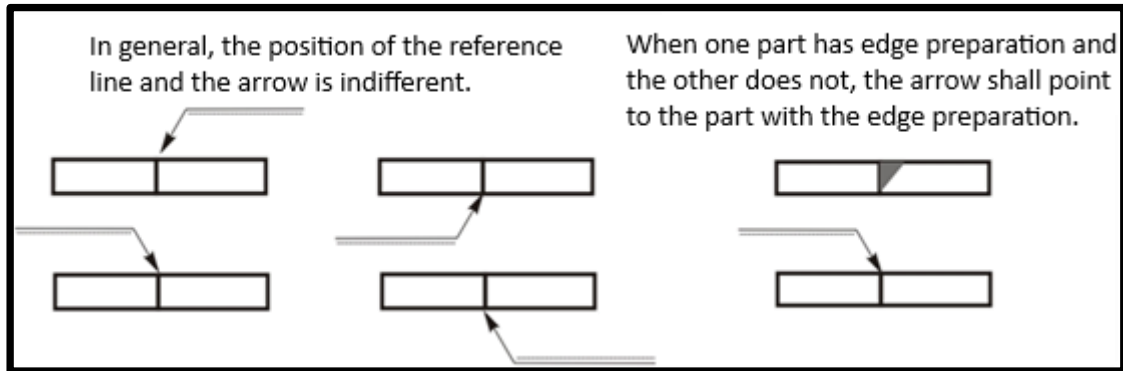


Figure 14 Meaning of the position of the arrow line

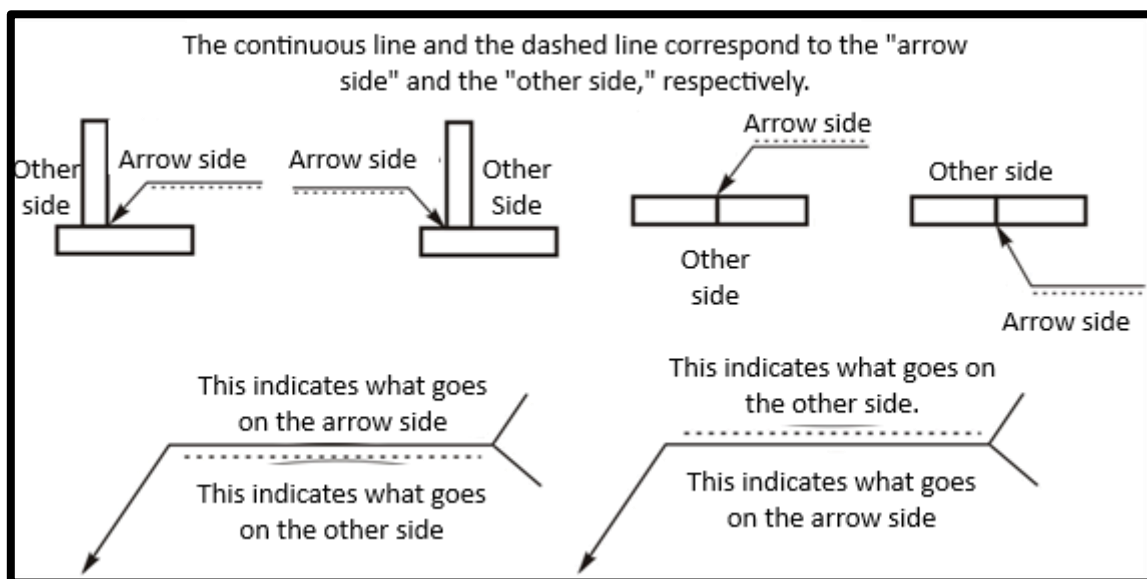


Figure 15 Meaning of the continuous line

4.2.2 Commonly used brazing symbols and their interpretation

They indicate the type of weld and the edge preparation. In general, they provide a schematic representation of the weld bead's shape

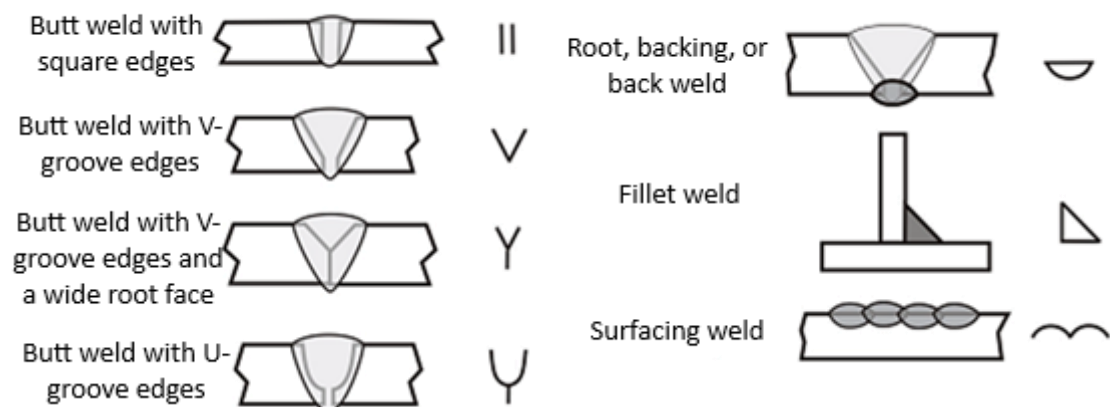


Figure 16 Commonly used symbols

Combinations of symbols are commonly used when welding is performed on both sides or when different types of welds.

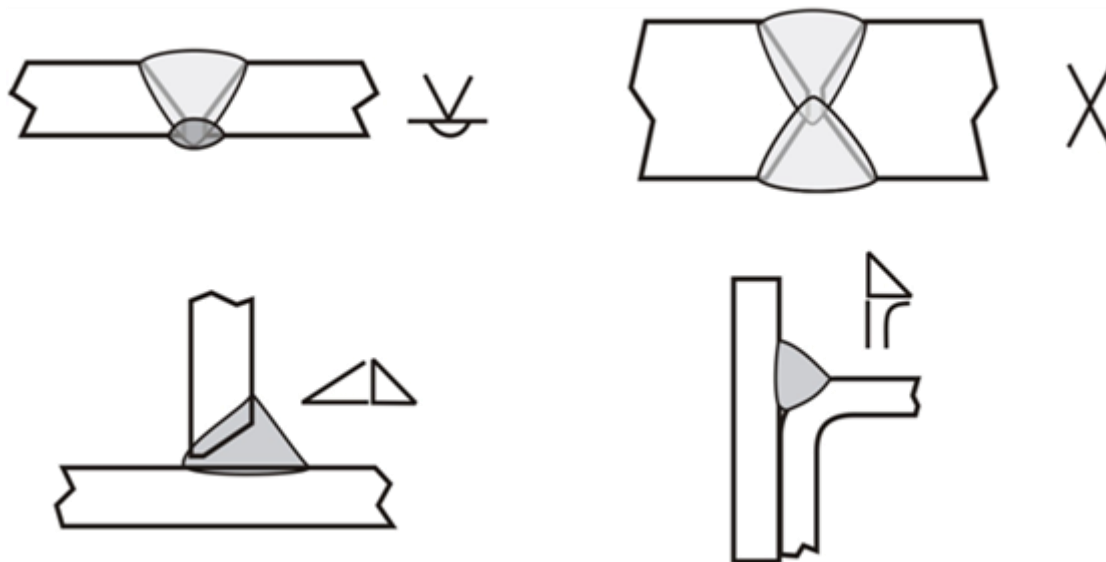


Figure 17 Common combination of symbols

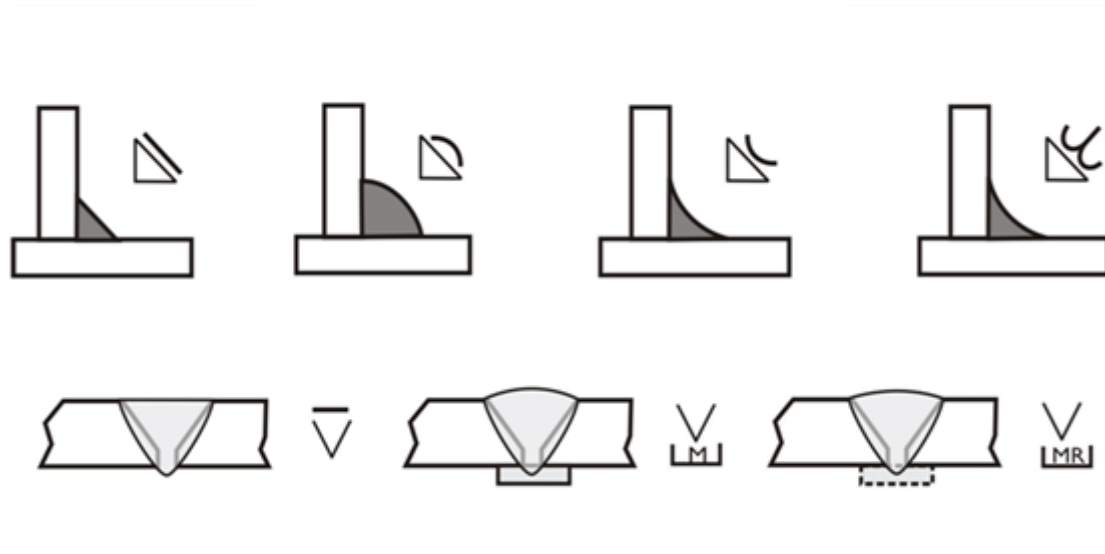


Figure 18 Common combination of symbols

4.2.3 Dimensions

The main dimensions pertain to the cross-section of the weld bead and its length. When these need to be indicated, those relating to the cross-section are placed before the basic symbol, and those relating to length after the symbol.

Butt joints are understood to be continuous along the joint and to have complete penetration, so measurements are generally not specified. In the case of partial penetration joints, the value of the penetration should be indicated to the left of the symbol.

The cross-section of fillet welds can be specified by the measurement of the throat (a) or by the measurement of the leg (z). To avoid ambiguities, the measurement must always be preceded by the corresponding letter (a or z). To indicate penetration in fillet welds, the letter s is used, followed by the value of the penetration and the measurement of the apparent throat

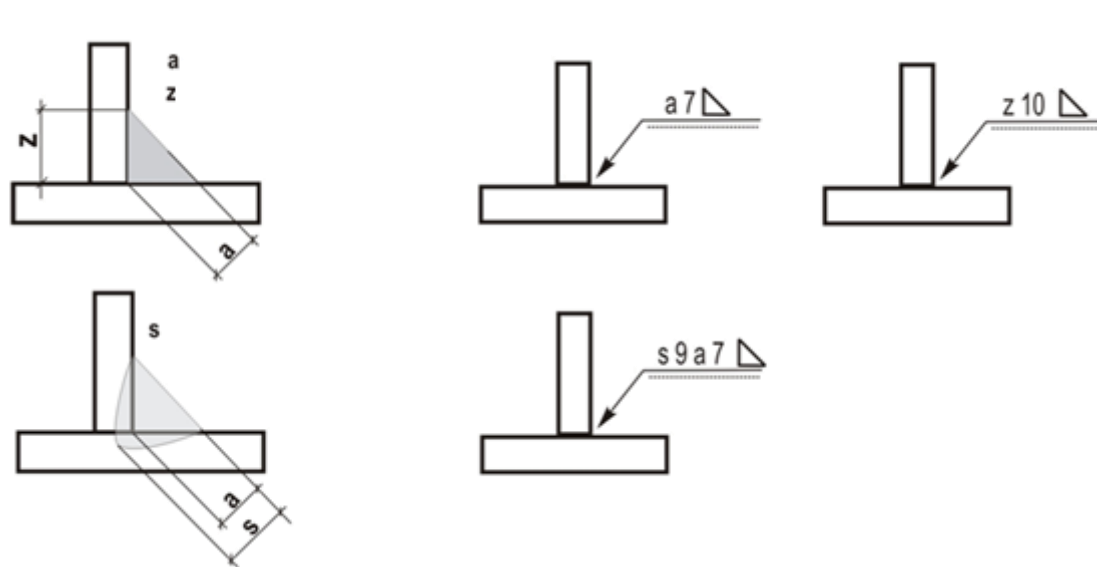


Figure 19 Position of dimensions in the reference line

4.2.4 Additional Indications

Although the standard recommends avoiding cluttering drawings with unnecessary or questionable indications, in addition to the shape and dimensions of weld beads, it is possible to specify the welding process, the required quality level, the welding position, the applicable procedure, the time when the welding should be performed, the filler materials, and so on. When used, these details are placed at the tail of the reference line.

Two commonly used additional indications are those specifying welding around the entire perimeter and welding on site.

To adapt drawings made according to the previous version of this UNE EN ISO 2553 standard, it is sufficient to add the dashed line where appropriate and write “a” or “z”, as necessary, before the measurement of fillet welds.

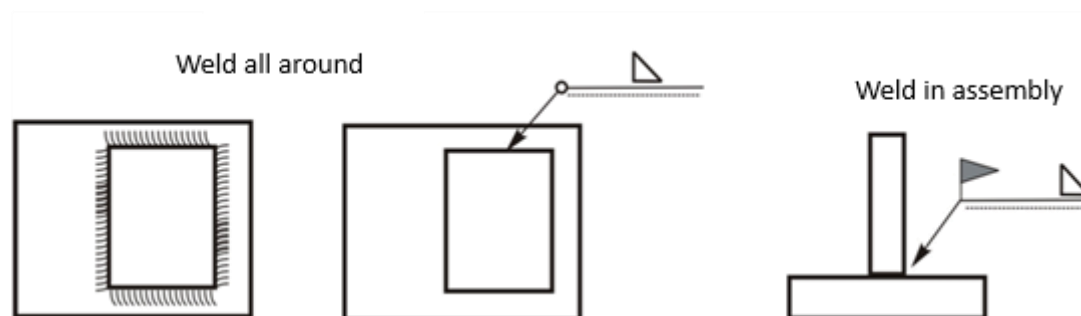


Figure 20 Commonly used additional indications

5 Introduction and Importance of Brazing Procedure Specifications (BPS)

5.1 Scope of ISO 17779:2021

ISO 17779:2021 sets forth requirements for the specification and qualification of brazing procedures for joining metallic materials. The document details the procedures for brazing test pieces, testing specimens, identifying essential variables and their qualification ranges, establishing acceptance criteria, and documenting both the Brazing Procedure Qualification Record (BPQR) and the Brazing Procedure Specification (BPS). General guidelines on quality requirements for brazing are provided in Annex A. Notably, the document does not address testing for residual stresses, corrosion resistance, or impact properties. This standard applies to a variety of brazing processes, as outlined in ISO 857-2 and ISO 4063:2009, encompassing methods such as infrared, flame, laser beam, electron beam, induction, resistance, diffusion, furnace, vacuum, dip-bath, salt-bath, flux bath, immersion, and arc weld brazing. The principles may also extend to other brazing processes and materials not specifically listed. However, this document excludes procedures for aerospace applications, which are covered under ISO 11745.

5.2 Test Piece Preparation and Requirements

The test piece or pieces must be brazed using a joint design proposed in the preliminary Brazing Procedure Specification (pBPS) and should represent the intended production. If the application standard does not specify the shape and dimensions of the test piece, these should be agreed upon by the relevant parties. Typically, test pieces feature basic lap or butt joints in sheet material or sleeve joints in tubes, with examples provided in Figure 21, Figure 22, Figure 23, Figure 24 and Figure 25. The size must be adequate to accommodate all required tests. Additional test pieces may be prepared for supplementary tests or retesting. Preparation and brazing of the test pieces should follow the pBPS and take place under production-like conditions. The brazing and subsequent testing must be witnessed by an examiner or qualified examining body.

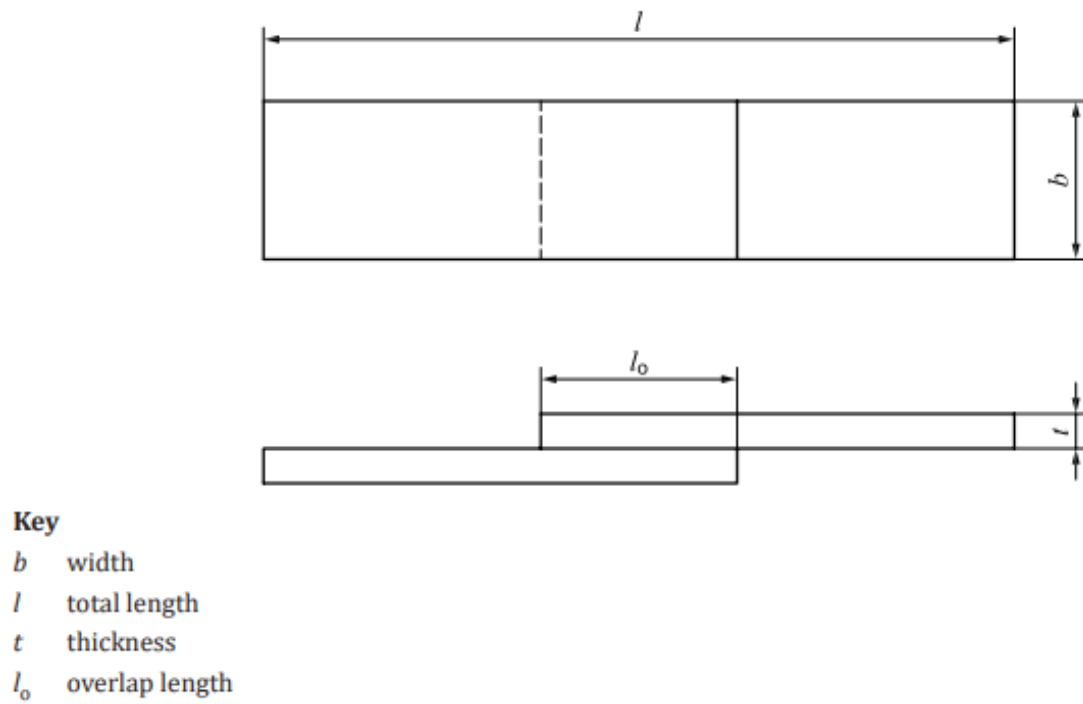


Figure 21 Test piece - Lap Joint [3]

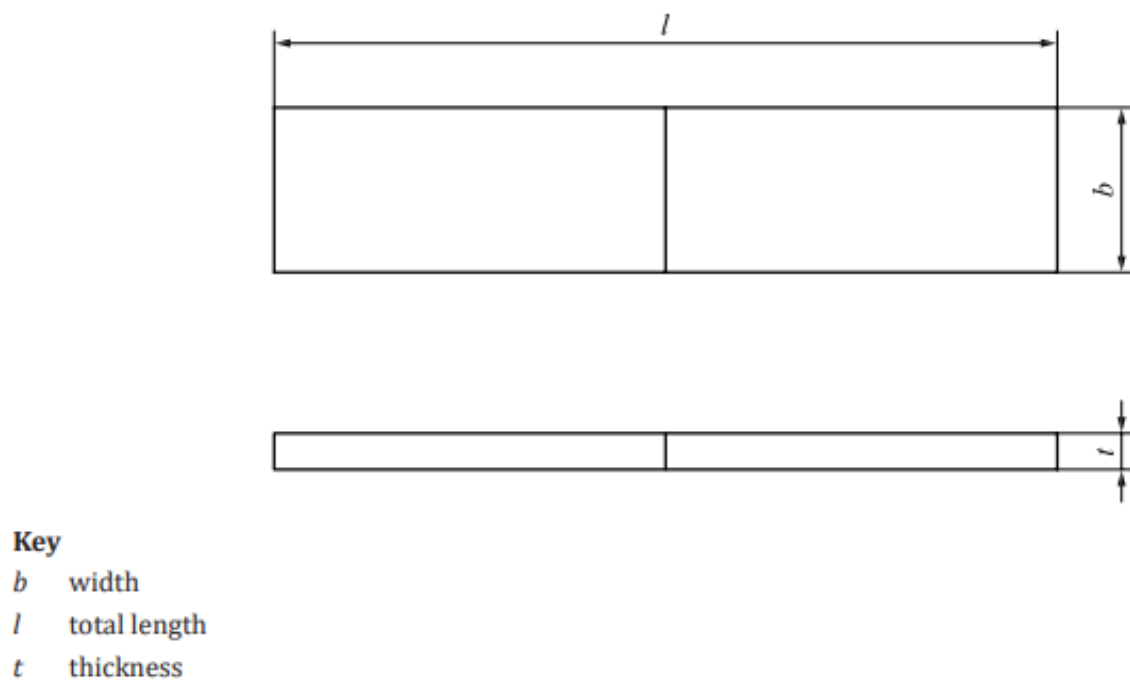
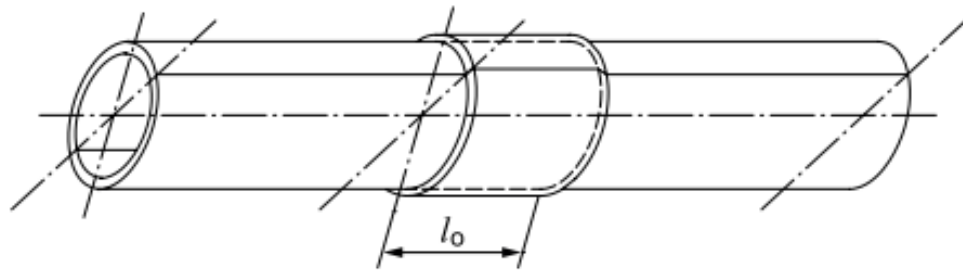


Figure 22 Test piece - Butt joint[3]



Key

l_o overlap

Figure 23 Test piece - Simple lap joint [3]

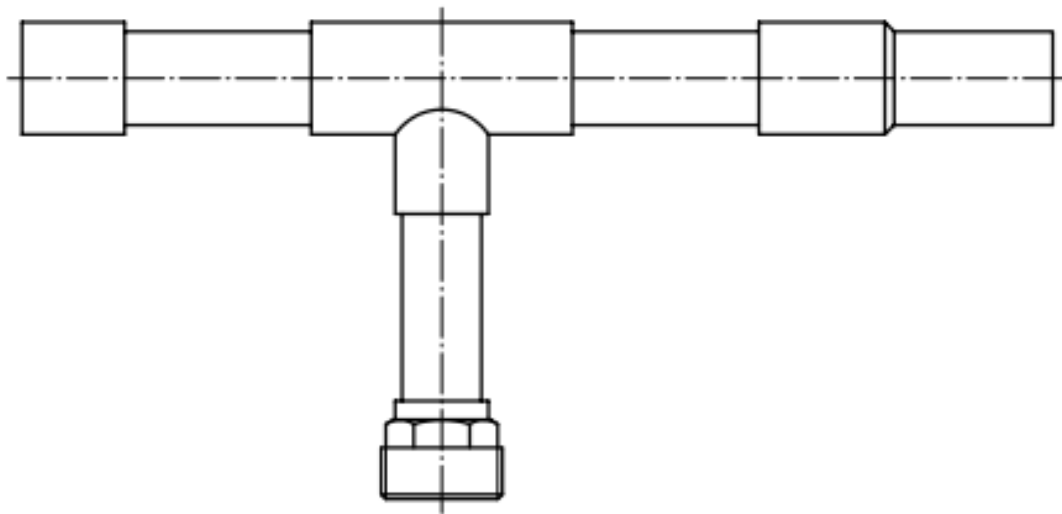
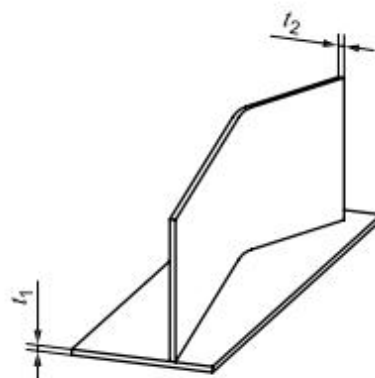


Figure 24 Test piece - Multiple joints[3]



Key

t_1 thickness of first component

t_2 thickness of second component

Figure 25 Test piece - T-joint[3]

5.3 Examination and Testing

Testing of brazed joints should, at a minimum, comply with Table 10, EN 12797, and EN 12799. Application standards may require additional tests, such as longitudinal tensile tests, volumetric testing (radiographic or ultrasonic), corrosion tests, or chemical analysis. Test specimens should conform to the shapes and dimensions specified in EN 12797, EN 12799, or equivalent standards. If these are not specified, they must be agreed upon by the contracting parties.

Non-destructive testing should follow the guidance in Table 10 and be performed before cutting the test specimens. Visual inspections should adhere to EN 12799 or equivalent standards, and radiographic testing, if needed, should also follow these standards.

Destructive testing is to be performed as outlined in Table 10. Bend testing requires one specimen from each surface: the first surface (from which the filler metal is applied) and the second surface (the opposite side). For T-joints, refer to Figure 26 Types of configuration of transverse bending testing for T-joint for configuration details. Peel and shear testing must comply with EN 12797 or equivalent standards, with shear specimens expected to fail in the weakest parent material unless otherwise specified. If the specimen fractures in the braze metal while requirements are met, the overlap length is inadequate and the joint design should be revised. Transverse tensile testing procedures and specimens must also follow EN 12797 or equivalent standards, and tensile strength must meet the minimum specified for the weaker parent material in the annealed condition, or 95% thereof if the specimen fails in the parent material.

Table 10 Examination and testing of the test pieces [3]

Test piece	Type of test	Extent of testing
T-joint	Visual, and Metallographic, or Bend	100 % 2 sections ^a 2 specimens ^b
Lap joint	Visual, and Metallographic, and Shear, or Peel	100 % 2 sections ^a 2 specimens 2 specimens
Butt joint	Visual, and Metallographic, and Tensile, or Bend	100 % 2 sections ^a 2 specimens 2 specimens ^b
^a Normally, macro sections are sufficient. However, micro sections can be required.		
^b One first surface and one second surface test.		

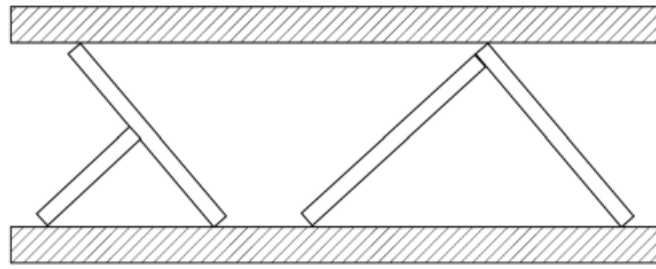


Figure 26 Types of configuration of transverse bending testing for T-joint [3]

5.4 Acceptance Criteria and Retesting

Unless specified otherwise, acceptance of imperfections found during testing must be assessed according to ISO 18279:2003. A brazing procedure is considered qualified if imperfections in the test piece are within quality level B of ISO 18279:2003, except for excess braze metal (6BAAA), where quality level C applies. No imperfection should pass through the joint length.

If a test piece fails visual or non-destructive testing requirements, one additional piece may be prepared and tested. Failure of this retest means the procedure qualification has failed. For destructive testing failures due to braze imperfections, two additional specimens must be tested for each failed sample. These additional specimens may come from the same or a new test piece, provided sufficient material is available. If either retest fails, the procedure qualification is not successful.

5.5 Essential Variables and Range of Qualification

All conditions in this part must be met to comply with the standard. Changes outside the specified ranges require a new qualification test. Each qualification test only applies to one brazing process; switching processes necessitates new testing. For global heating processes, the brazing temperature must remain within the BPS-specified range. Furnace atmospheres, fuel gases, and flames must remain consistent with those used in qualification.

Brazing one product type qualifies other types as per Table 11. The BPS should provide comprehensive instructions, including tolerances for essential variables, which may not match the full qualification ranges in the BPQR but should be practical, such as for gap or overlap length. A BPS is considered preliminary until validated by a BPQR. Required information includes manufacturer and BPS identification, reference to BPQR or other documents, parent material designation and standard, material group, material dimensions, joint design sketch, brazing process, filler material flow direction, filler and flux designation and type, fuel gas details, brazing temperature, furnace atmosphere, post-braze heat treatment, joint preparation and cleaning methods, and degree of mechanization.

Table 11 Range of qualification for product type[3]

Product type for test piece	Range of qualification
Plate	Plate
Pipe	Pipe and plate

Table 12 Range of qualification for type of joint[3]

Type of joint in test piece	Range of qualification
T-joint	T-joint
Lap joint	Lap joint
Butt joint	Butt joint

5.6 Qualification of Materials, Filler Metals, and Flux

Testing with two different M-number groupings in a single test piece qualifies brazing procedures for combinations within and between those groupings, provided the same filler metal, flux, atmosphere, and process are used. Filler metals must be classified according to ISO 17672 or equivalent standards, and qualification of one class covers others within that class. Only the tested form of filler metal (e.g., preformed ring, paste) is qualified. Fluxes must be classified by ISO 18496 or equivalent; qualification only covers brazing within the same classification.

Table 13 Range of qualification of parent material[3]

Test piece material	Range of qualification ^{a,b}
100, 110, 120, 170	100, 110, 120, 170
130, 140, 150, 160, 180	130, 140, 150, 160, 180
200, 210, 220	200, 210, 220
300, 310, 320, 330, 340, 350, 360	300, 310, 320, 330, 340, 350, 360
400, 410, 420, 430	400, 410, 420, 430
500	500
600	600
700	700
800	800
^a For a test piece material used for brazing procedure qualification, the brazing procedure is qualified to braze all materials and all combinations of materials given in the same row. ^b When test piece material from two rows are used for brazing procedure qualification, the brazing procedure is qualified to braze all material combinations in each row and combinations between those rows.	

Filler metal application qualifies other applications as detailed in Table 14. Qualification ranges for parent material thickness are provided in Table 15. For dissimilar thicknesses, qualification is based on each part individually. For lap joints, the tested overlap is the minimum qualified, and joint gap must follow the filler metal manufacturer's recommendations.

Table 14 Range of qualification for brazing filler application [3]

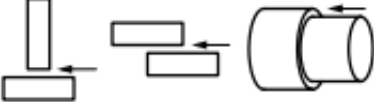
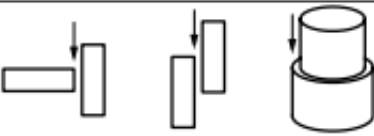
Test piece brazing filler application	Range of qualification
Face fed	Face fed
Pre-placed	Pre-placed
NOTE "Face fed" is also known as "applied to the mouth of the joint", which can be manually or mechanically fed.	

Table 15 Range of qualification for parent material thickness [3]

Thickness of test piece t	Range of qualification
$t < 3$	0,5t to 2t
$3 \leq t < 10$	1,5 to 2t
$10 \leq t \leq 25$	5 to 2t

Filler metal flow direction qualification is defined in Table 16, with other directions needing separate qualification. For procedure qualification, a maximum angular deviation of $\pm 15^\circ$ from the qualified flow position is permitted.

Table 16 Range of qualification for filler metal flow direction[3]

Illustrations	Filler metal flow direction of the test piece	Range of qualification
	Horizontal flow	Horizontal flow and vertical down-flow
	Vertical down-flow	Vertical down-flow
	Vertical up-flow	All flow directions

5.7 Additional Variables and Manufacturer Responsibility

A test with any branch angle qualifies all branch angles. Parent materials are grouped by M-numbers to minimize qualification tests; materials outside these groupings require separate qualification. Any changes to post-braze heat treatment necessitate requalification of the BPS.

A manufacturer's qualification of a pBPS is valid for brazing performed in workshops or sites under the same technical and quality control. This means the manufacturer retains full responsibility for all brazing conducted to the qualified specification.

5.8 Brazing Procedure Qualification Record (BPQR)

The BPQR documents the results of all test pieces, including any retests, and must include all relevant BPS items plus details of any features that would cause rejection of the acceptance criteria. If no such features or unacceptable test results are found, the BPQR is considered qualified and must be signed and dated by the examiner or examining body. The BPQR should follow a standard format for uniform presentation and assessment of the brazing procedure and test results.

5.9 Practical Exercise: Completing a Brazing Procedure Specification (BPS)

This exercise is designed to provide hands-on experience in preparing a Brazing Procedure Specification (BPS) based on a hypothetical brazing application. Please use the following scenario and fill out the required BPS details as outlined in the context above.

- **Scenario:**

1. You are tasked with developing a BPS with the following variables:

- Parent Material: Two copper pipes (Cu-DHP, EN 12449, M-number group M12)
- Material Dimensions: Wall thickness of each pipe is 2 mm; overlap length is 12 mm
- Joint Type: Lap joint configuration
- Joint Design Sketch: Description: Two cylindrical copper pipes arranged in a lap joint, with a 12 mm overlap; edges are mechanically cleaned and degreased prior to assembly.
- Brazing Process: Oxy-acetylene torch brazing in air; manual operation
- Filler Metal: Silver-based alloy, classified under ISO 17672, supplied as preformed ring
- Flux: Type FH10 per ISO 18496
- Fuel Gas: Oxygen-acetylene
- Brazing Temperature: 680°C
- Atmosphere: Air
- Post-Braze Heat Treatment: None
- Joint Preparation: Mechanical cleaning and degreasing
- Filler Metal Flow Direction: Axial (along the axis of the pipe)
- Manufacturer and BPS Identification: [To be completed by manufacturer]
- Reference to BPQR or Related Documents: [To be completed by manufacturer]

This exercise will help reinforce your understanding of the essential BPS variables and the practical considerations in documenting a brazing procedure. On Table 17, there is a template for making the document.



Table 17 BPS example[3]

BPS reference No.:	
Manufacturer's name and address:	
Manufacturer's brazing procedure (BPQR No.):	

Brazing process:		Method of joint preparation:	
Joint type:		Material thickness (mm):	
Parent material(s) and specification(s):		Outside diameter (mm):	
Degree of mechanization: (manual/mechanized/automatic)		Brazing position:	
Gap (mm):		Overlap, L (mm):	

Joint design and preparation details (sketch):

Brazing filler metal type and specification:		Method of pre-braze cleaning:	
Brazing filler metal form:		Method of post-braze cleaning:	
Method of filler metal supply:		Nozzle size and number:	
Flux type and specification:		Heating gas type:	
Flux form:		Heating gas pressure:	
Method of flux supply:		Preheat temperature:	
Jig/fixture details:		Post-braze heat treatment:	

Manufacturer's representative Name, date and signature:	Examiner/Examining body Name, date and signature:

6 Visual inspection criteria and Avoidance of imperfections on brazed joints

6.1 Visual examination

6.1.1 General Requirements for Visual Inspection

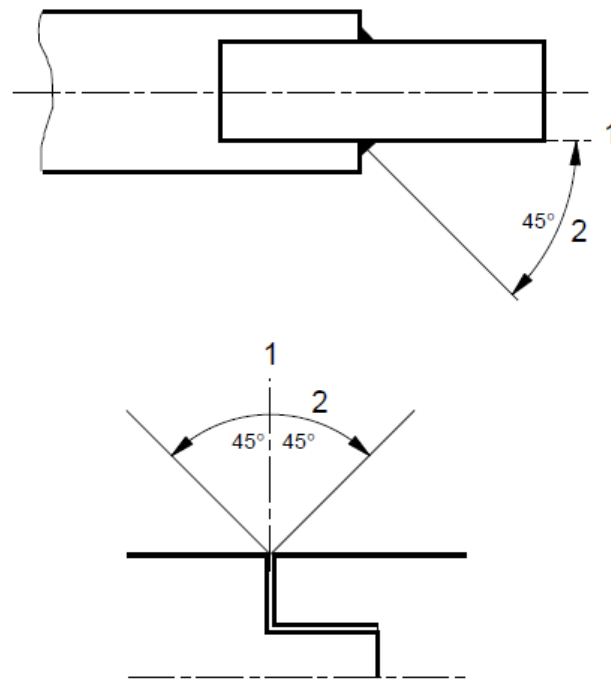
Simple visual examination serves as the most fundamental and widely applied technique for non-destructive testing. This method, as described in this section, specifically addresses the assessment of joint quality and does not encompass dimensional measurements.

6.1.1.1 Design Considerations for Inspection

During the design phase, it is essential to ensure that the structure provides sufficient access for effective visual inspection. Adequate access facilitates comprehensive examination and contributes to the reliability of the inspection process.

6.1.1.2 Accessibility of Joints

Prior to initiating any visual inspection, it is necessary to determine which joints and fillet welds are open for assessment. The criterion for accessibility should allow for satisfactory inspection, whether directly by eye or through the use of a mirror, as illustrated in Figure 27.



Key
 1 Axis
 2 Viewing angle

Figure 27 Access for visual inspection: joints to be viewable within a stated angle of joint axis or exit plane [4]

6.1.1.3 Principle of Visual Examination

The process of visual examination involves a detailed inspection of the brazed joint as well as the adjacent parent material. This assessment is conducted using both unaided and aided visual methods to evaluate the joint's overall appearance, soundness, and contour.

6.1.2 Qualification of Personnel for Visual Examination

Personnel responsible for conducting visual examinations must meet specific qualifications to ensure the reliability of the inspection:

1. Knowledge of the Braze Process and Imperfections:
2. Inspectors must be informed about the braze process employed and be familiar with the potential imperfections that may arise.
3. Vision Testing:
4. Their vision must be tested according to the standards outlined in section 6.3 of EN 473:1993.
5. Instruction in Specific Requirements:
6. Inspectors should receive training focused on the particular requirements related to visual examination.

7. Instruction in General Application Standards:
8. They must also be instructed in the relevant general standards governing the application of visual inspection.

When training records are maintained, they should verify compliance with all the above requirements. Additionally, these records must include a statement from a supervisor confirming that the inspector has attained an acceptable level of proficiency. No further qualifications are required beyond those specified above for personnel performing visual examinations.

6.1.3 Requirements Specific to Visual Examination

Before conducting any visual examination, specific requirements must be clearly established to ensure the consistency and reliability of the inspection process. The following considerations must be addressed:

6.1.3.1 Pre-Examination Requirements

1. **Manufacturing Stage for Examination:** Determine the precise stage in the manufacturing process at which the visual examination will be performed. This should include consideration of whether the inspection will take place in-line with production.
2. **Surface Preparation Requirements:** Specify requirements for preparing the surface prior to inspection. Note: Generally, no surface preparation is required after fluxless brazing processes.
3. **Minimum Relevant Imperfection Size:** Define the smallest imperfection size that is considered relevant for the inspection. Unless stated otherwise, the recommended minimum size is 0.5 mm).
4. **Extent of Visual Examination:** Since some fillets are hard to access or require special inspection methods, the specific inspection scope for each workpiece must be clearly defined before examination. Inspection sites should be marked on the assembly drawing or a separate detailed drawing, which must also include or reference acceptance criteria.
5. **Acceptance Criteria:** Set forth the standards for acceptance.
6. **Written Inspection Procedure:** Determine if a documented procedure for inspection is required.
7. **Reporting Requirements:** Clarify the necessary documentation and reporting for the examination results.
8. **Additional Aids to Visual Inspection:** Identify any supplementary aids required for visual inspection beyond those specified in section 6.1.4.

6.1.3.2 Information Required Before Examination

Before initiating the visual examination, it is essential that the operator is furnished with all pertinent details necessary for conducting a thorough and consistent inspection. Specifically, the operator must have access to all information regarding the requirements specific to the examination to ensure clarity regarding the inspection criteria and process.

In addition, if a written inspection procedure is applicable, it must be provided to the operator before the examination begins. Supplying this documentation in advance ensures that the inspection is performed in accordance with the established standards and that any procedural requirements are clearly understood by the operator prior to commencing the examination.

6.1.4 Inspection Aids and Equipment

To ensure a thorough and effective visual inspection, specific aids and equipment are likely to be required. The following items should be available and utilized as appropriate during the examination process:

- **Suitable Illumination:** Adequate lighting is essential to clearly observe all areas under inspection.
- **Wide-Angle Low-Magnification Viewer:** A standard universal bench-mounted device with low magnification (approximately 5x) should be used. This device should allow both hands to remain free for manipulation and may also include integrated illumination for enhanced visibility.
- **Comparison Gauge for Minimum Relevant Imperfection Size:**
 - A mounted wire of the specified minimum diameter can be used for direct comparison with imperfections. The end of the wire may be bent to facilitate proper alignment with the primary axes of any detected imperfection.
 - Alternatively, an 8x magnification loupe equipped with a graticule may be employed to accurately assess the size of imperfections.

For joints that are only partially accessible, a plain small mirror—such as a dental mirror—should be employed. This tool enables the operator to inspect areas that would otherwise remain hidden, ensuring a comprehensive visual assessment of all joint surfaces.

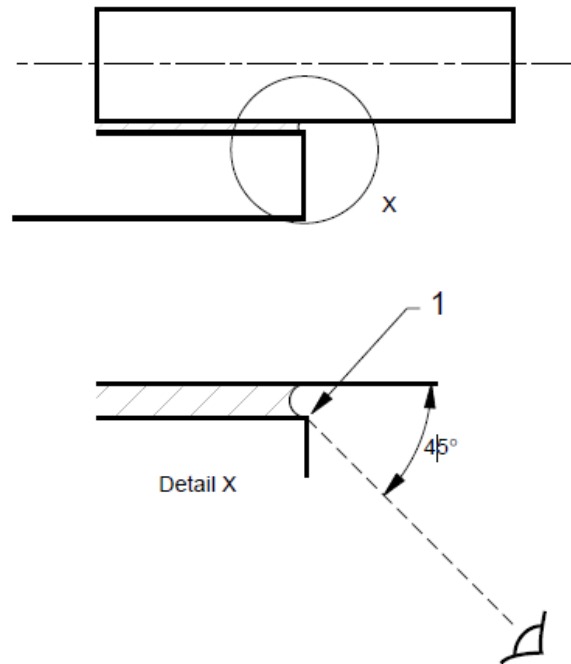
In situations where portions of the workpiece are obscured by shadows or lack adequate natural light, localized illumination devices are necessary. Optic fiber lightguides or similar equipment should be utilized to provide focused lighting, thereby improving visibility and allowing for a thorough inspection of all relevant areas.

When marking of individual joints is required during the inspection process, only approved methods should be used. Specifically, waterproof felt marker pens or other specified marking tools are to be utilized to clearly identify joints without compromising the integrity of the workpiece.

6.1.5 Extent of Visual Inspection on Each Workpiece

Visual inspection procedures must accommodate the fact that many workpieces contain fillets that are either difficult to access or require specialized techniques for thorough examination. As such, the scope of inspection for each workpiece must be clearly defined prior to initiating the inspection. This ensures consistency and removes ambiguity, preventing the extent of inspection from being left to the personal discretion of the inspector.

For clarity and reference, the designated inspection sites should be indicated on the assembly drawing. In situations where assemblies are complex, a separate drawing may be prepared specifically to outline these inspection locations. Additionally, these drawings must either specify or reference the acceptance criteria that will be used to evaluate the workpiece.



Key

- 1 Bottom of recess to be visible at 45 ° to the joint axis

Figure 28 Access for visual inspection: recessed fillet, when recessed fillets are permitted [4]

6.1.6 Examination Procedure for Brazed Joints

6.1.6.1 Use of Magnification and Illumination

Low-power magnification devices, such as bench-mounted wide-angle 5x magnifiers, should be considered to help reduce eye strain and enhance productivity. These devices allow both hands to remain free, enabling the operator to handle and manipulate workpieces as needed for optimal viewing of fillets. For joints located in shaded or poorly lit areas, fiber optic light guides or similar equipment shall be used to provide adequate illumination and improve visibility during inspection.

6.1.6.2 Minimum Imperfection Size Gauge

A gauge for minimum imperfection size must be utilized during inspection. Its purpose is to ensure that the detection of imperfections does not depend solely on the visual acuity of individual operators, thereby standardizing the minimum size of imperfections recognized across all inspections.

6.1.6.3 Segregation of Workpieces

Appropriate measures must be in place to separate uninspected workpieces from those that have already been inspected. Additionally, there should be clear segregation between acceptable and unacceptable workpieces to maintain organization and prevent mix-ups during the inspection process.

6.1.6.4 Methodical Inspection Planning

When inspecting workpieces that contain numerous joints, an organized plan must be implemented to ensure a systematic approach to inspection. This helps guarantee that all joints are assessed thoroughly and consistently.

6.1.6.5 Marking Inspected and Defective Joints

It is recommended that joints be marked in a manner that clearly distinguishes those that have been inspected from those that have not, as well as to identify any joints found to be defective. Felt marker pens, with a composition that will not harm the workpiece, are suggested for this purpose. Green spots may be used to indicate acceptable joints, while red spots should denote unacceptable joints.

6.1.7 Reporting of Test Results and Inspection Information

Comprehensive records must be maintained to document the extent of inspection activities, the acceptance criteria used, and the outcomes of each inspection. In situations where it is agreed that a separate inspection report is necessary, apart from other records, the report should include at least the following information:

- Name of Inspection Organization:
- The official name of the organization responsible for conducting the visual inspection.
- Workplace Identification:
- The name of the workplace and/or the associated drawing number.
- Batch Identification:
- A unique identification number for the batch of components addressed in the report.
- Extent of Inspection:
- A description of how much of the batch was inspected. If this information is covered in a written procedure, it is sufficient to reference the procedure and specify its issue number. Alternatively, a drawing may be referenced, provided it gives enough specific information for inspection purposes.
- Acceptance Criteria:
- The specific criteria used to determine acceptance. As with the extent of inspection, referencing a written procedure or a suitable drawing is sufficient if it contains all necessary details.
- Inspection Results:

- The total quantity of components inspected in the batch, along with the number that passed inspection.
- Inspector's Details:
- The name and signature of the individual who performed the inspection.
- Date of Inspection:
- The date on which the inspection was carried out.

6.2 Classification of imperfections in brazed joints

Imperfections that may arise during the brazing process are systematically categorized to facilitate their identification and assessment. These imperfections are divided into six primary groups:

- Group I: Cracks
- Group II: Cavities
- Group III: Solid Inclusions
- Group IV: Bonding Imperfections
- Group V: Shape and Size Imperfections
- Group VI: Miscellaneous Imperfections

Each imperfection is assigned a specific designation and is further described in Table 1. In addition to these groups, imperfections are distinguished based on their location as either internal or external within brazed joints.

6.2.1 Internal Imperfections

Internal imperfections are those that occur within the brazed joint and are not typically visible from the surface. Examples of internal imperfections include:

- Crack(s)
- Filling imperfection
- Solid inclusion
- Gas entrapment
- Flux inclusion
- Lack of fusion
- Excessive alloying of filler material and parent material (sometimes referred to as erosion)

6.2.2 External Imperfections

External imperfections are those that are evident on the surface of the brazed joint. Examples of external imperfections include:

- Underfill
- Crack(s)
- Surface-breaking porosity
- Incomplete fillet

- Overlap
- Localized melting
- Rough surface of seam
- Flux seepage
- Discoloration
- Spatter
- Residual flux
- Surface erosion of parent material

This classification framework assists inspectors and engineers in systematically identifying and documenting imperfections, thereby supporting consistent evaluation and acceptance of brazed joints.

Table 18 Clasification of imperfections [5]

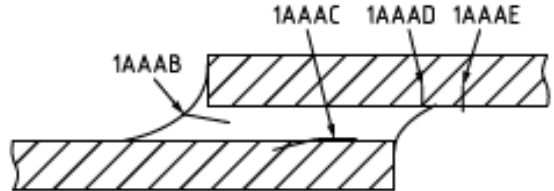
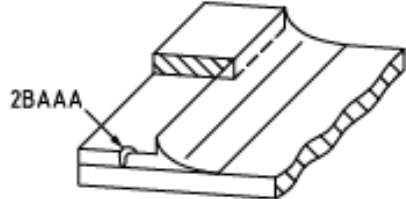
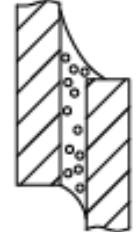
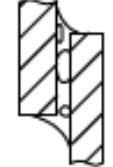
Designation	Description	Remarks	Drawing
I Cracks			
1A ^a AAA 1A ^a AAB 1A ^a AAC 1A ^a AAD 1A ^a AAE	Crack	Limited separation of the material, predominantly two-dimensional extension. A crack can be longitudinal or transverse. It can lie in one or more of the following: — in the braze metal — at the interface and including the diffusion zone — in the HAZ — in the unaffected parent material	
II Cavities			
2BAAA	Gas cavity	Gas-filled cavity	
2BGAA 2BGGA 2BGMA 2BGHA	Gas pore	Spheroidal gas inclusion It can occur as: — uniformly distributed porosity — localized (clustered) porosity — linear porosity	
2LIAA	Large gas pocket	Large voids may be the width of the joint with elongated shape	
^a In the case of an intergranular crack, change this second symbol 'A' to the symbol 'F'. In the case of a transgranular crack, change this second symbol 'A' to the symbol 'H'. ^b These imperfections often occur together.			

Table 19 Clasification of imperfections [5]

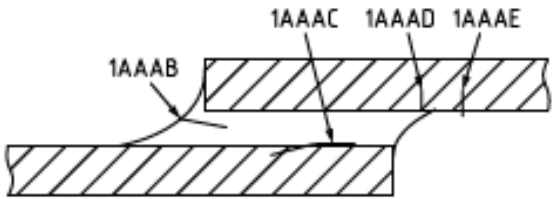
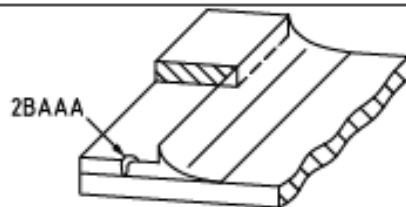
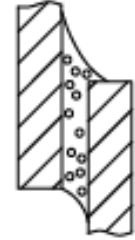
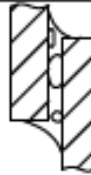
Designation	Description	Remarks	Drawing
I Cracks			
1A ^a AAA 1A ^a AAB 1A ^a AAC 1A ^a AAD 1A ^a AAE	Crack	Limited separation of the material, predominantly two-dimensional extension. A crack can be longitudinal or transverse. It can lie in one or more of the following: — in the braze metal — at the interface and including the diffusion zone — in the HAZ — in the unaffected parent material	
II Cavities			
2BAAA	Gas cavity	Gas-filled cavity	
2BGAA 2BGGA 2BGMA 2BGHA	Gas pore	Spheroidal gas inclusion It can occur as: — uniformly distributed porosity — localized (clustered) porosity — linear porosity	
2LIAA	Large gas pocket	Large voids may be the width of the joint with elongated shape	
^a In the case of an intergranular crack, change this second symbol 'A' to the symbol 'F'. In the case of a transgranular crack, change this second symbol 'A' to the symbol 'H'. ^b These imperfections often occur together.			

Table 20 Clasification of imperfections [5]

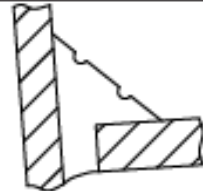
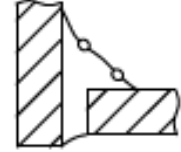
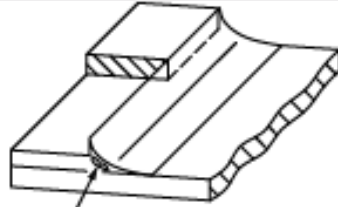
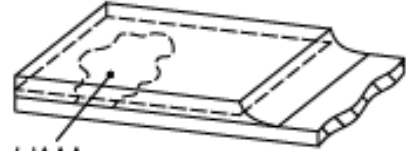
Designation	Description	Remarks	Drawing
2BALF ^b	Surface pore	Gas pore breaking the surface	
2MGAF ^b	Surface bubble	Gas pore near the surface, which results in swelling	
III Solid inclusions			
3AAAA 3DAAA 3FAAA 3CAAA	Solid inclusion	Inclusion of foreign metal or non-metallic particles in the braze metal Could be possible to divide into: — oxide inclusion — metallic inclusion — flux inclusion	 3AAAA
IV Bonding imperfections			
4BAAA	Bonding imperfection	No bonding or inadequate bonding between the braze metal and the parent material	
4JAAA	Filling imperfection	Incomplete filling of the gap	 4JAAA
^a In the case of an intergranular crack, change this second symbol 'A' to the symbol 'F'. In the case of a transgranular crack, change this second symbol 'A' to the symbol 'H'. ^b These imperfections often occur together.			

Table 21 Classification of imperfections [5]

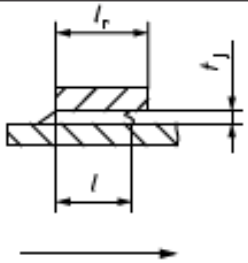
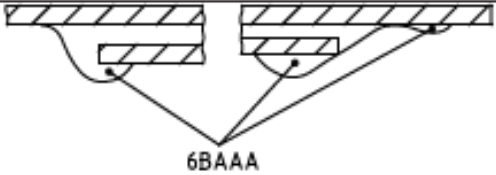
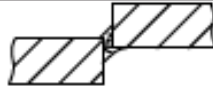
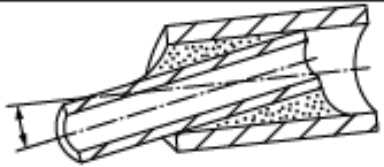
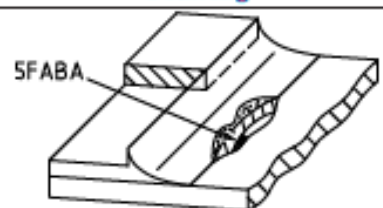
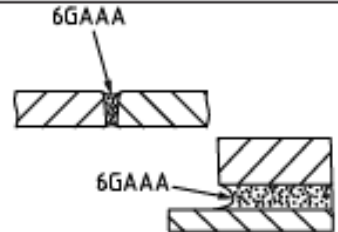
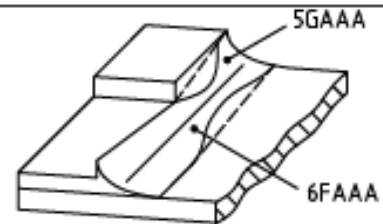
Designation	Description	Remarks	Drawing
4CAAA	Incomplete penetration	The braze metal has failed to flow through the required length of the joint	 The arrow indicates the direction of flow through the joint
V Shape and size imperfections			
6BAAA	Excess braze metal	Braze metal has spilled over onto parent material solidifying as a bead or a thick layer	 6BAAA
5AAAA	Imperfect shape	Departure from the prescribed shape of the brazed joint	
5EIAA	Linear misalignment (linear offset)	The components are parallel but offset	
5EJAA	Angular misalignment	The components form an angle deviating from the required value.	
5BAAA	Distortion	Unwanted change in the shape of the brazed assembly	
^a In the case of an intergranular crack, change this second symbol 'A' to the symbol 'F'. In the case of a transgranular crack, change this second symbol 'A' to the symbol 'H'. ^b These imperfections often occur together.			

Table 22 Classification of imperfections [5]

Designation	Description	Remarks	Drawing
5FABA	Localized melting (or melt-through)	Through-going hole in the brazed joint or next to it	
7NABD	Fused parent material surface	Fused surface of the brazed assembly in the region of the joint	
7OABP	Erosion by filler metal	Erosive damage to the surface of the brazed assembly	
6GAAA	Recessed braze metal (recessed fillet)	The surface of the filler metal in the brazed joint is below the level of the joint opening The surface of the braze metal has sunk below the surface of the parent material	
5HAAA	Rough surface	Irregular solidification, liquation, etc.	
6FAAA	Insufficient or excessive fillet	Fillet out of specified size has formed	
5GAAA	Irregular fillet	Appearance of fillet variable	

^a In the case of an intergranular crack, change this second symbol 'A' to the symbol 'F'. In the case of a transgranular crack, change this second symbol 'A' to the symbol 'H'.

^b These Imperfections often occur together.

6.3 Acceptance Guidelines for Brazed Joints

The following acceptance guidelines should be considered when evaluating brazed joints to ensure proper inspection and quality control:

6.3.1 Flux and Flux Residues

When flux is used in the brazing process, it is crucial to specify the extent to which flux and flux residues must be removed to allow for a thorough inspection. The guidelines should detail the required level of cleaning appropriate to the brazing method employed.

6.3.2 Minimum Relevant Imperfection Size

Imperfections that have a maximum dimension smaller than a predetermined minimum size should be disregarded during evaluation. It is recommended that the minimum relevant imperfection size is 0.5 mm. Assemblies requiring higher integrity may need additional testing, such as leaktightness tests, to determine their acceptability for service.

6.3.3 Continuity of Fillets

Acceptance criteria must state whether complete or incomplete fillets are permitted. If incomplete fillets are allowed, the requirements should be described as clearly as possible to avoid ambiguity. For instance, specifying “incomplete fillets with x gaps maximum, each not exceeding y mm” is preferable to stating “incomplete fillets with gaps not exceeding 20% of total length.”

6.3.4 Recessed Fillets

Recessed fillets may result from brazing gaps that are at the upper limit for the process or from insufficient filler metal. Since it is difficult to estimate the depth of recess, acceptance should be determined using a defined criterion, such as the one shown in Figure 2.

6.3.5 Excess Filler Metal

If there is a requirement that filler metal must not encroach upon surfaces adjacent to the brazed joint, these areas should be precisely indicated in the assembly drawing. This serves as a guide for applying stop-off agents during preparation and is important for inspection after brazing.

6.3.6 Surface Erosion

Certain brazing processes, such as those involving aluminum, can lead to erosion of the parent metal by the filler metal. Where applicable, the acceptable degree of surface erosion should be documented using permanent records, such as sketches, photographs, or samples. These records should depict both acceptable and unacceptable conditions.

6.3.7 Cosmetic Appearance of Braze Fillets

If there are requirements concerning the cosmetic appearance of braze fillets, these should be established before inspection begins. Such requirements may influence the specifics and cost of the

brazing process. A permanent record, including sketches, photographs, or samples, should be created to illustrate both acceptable and unacceptable conditions in detail.

6.4 Avoidance of Imperfections—Common Causes

Brazing is a vital joining technique frequently employed in manufacturing due to its ability to produce robust, leak-proof joints. Nevertheless, imperfections that arise during brazing can undermine the integrity and performance of these joints. Recognizing and addressing the common causes of such flaws is crucial for consistently high-quality results.

6.4.1 Inadequate Surface Preparation

Poor cleaning of base metals is one of the most prevalent causes of imperfections in brazed joints. Residual oxides, oils, or dirt left on the surfaces can significantly impede the wetting and bonding of the filler metal. When contaminants are present, the filler metal may not adequately adhere to the base materials, resulting in joints that lack strength and durability.

To prevent these issues, it is essential that all surfaces are thoroughly cleaned and degreased before the brazing process begins. Oxides should be removed using appropriate chemical or mechanical methods. Meticulous surface preparation helps ensure optimal bonding and contributes to the overall integrity and performance of the brazed joint.

6.4.2 Incorrect Joint Clearance

Joint clearance plays a critical role in determining the quality and strength of a brazed joint. When the gap between the base metals is not within the recommended range, the effectiveness of the brazing process can be significantly compromised. If the joint gap is too wide, capillary action—which is essential for drawing the molten filler metal into the joint—becomes less efficient. In such cases, the filler metal may not adequately fill the gap, resulting in a weak or porous joint.

Conversely, if the joint gap is too narrow, the flow of the filler metal is restricted. This can prevent the filler metal from penetrating fully into the joint, leading to incomplete bonding and reduced joint strength. Both excessive and insufficient joint clearances can therefore undermine the integrity and reliability of the brazed assembly.

To ensure optimal results, it is important to maintain joint clearances within the recommended range, typically between 0.05 and 0.15 mm. Adhering to these guidelines promotes proper flow of the filler metal and contributes to the formation of strong, durable joints.

6.4.3 Improper Heating

Uneven or insufficient heating during the brazing process is a common source of imperfections that can significantly affect joint quality. When heat is not distributed uniformly across both base metals, it can lead to localized overheating, which may cause unwanted oxidation. Additionally, incomplete melting of the filler metal can occur, preventing it from properly flowing and bonding with the base materials. These conditions weaken the joint and reduce its overall reliability and performance.

To prevent these issues, it is essential to apply heat evenly to all parts of the base metals. Concentrating heat solely on the filler metal should be avoided, as this does not ensure thorough melting and consistent joint formation. Achieving uniform heating throughout the brazing process helps promote a strong, reliable bond between components.

6.4.4 Poor Filler Metal Selection

The selection of an unsuitable filler alloy for the base metals or for the specific service conditions can have detrimental effects on the quality and longevity of a brazed joint. When the filler metal is not compatible with the base materials, the resulting joint may exhibit brittleness, reducing its ability to withstand mechanical stress. Additionally, improper filler selection can make the joint more susceptible to corrosion, undermining both its reliability and durability in service.

To prevent these issues, it is crucial to choose filler metals that are compatible with both the base materials and the intended operating environment. Careful consideration of material properties and service requirements ensures that the brazed joint maintains its strength, resilience, and resistance to corrosion throughout its operational life.

6.4.5 Flux Issues

Problems with flux can significantly compromise the quality of a brazed joint. Common issues include incorrect application, contamination, or using an insufficient quantity of flux. These problems may result in oxidation of the base metals and poor wetting of the filler metal, both of which reduce the strength and reliability of the joint. Oxidation inhibits the proper flow of the filler metal, preventing it from bonding effectively with the base materials and potentially leading to weak or porous joints.

To prevent flux-related imperfections, it is important to select the correct type of flux for the specific materials and application. The flux should be applied evenly to all surfaces involved in the brazing process. Additionally, using fresh and uncontaminated flux is essential, as impurities can interfere with its effectiveness and negatively impact joint quality. Consistent and careful flux application helps ensure optimal brazing performance and the formation of strong, durable joints.

6.4.6 Environmental Contamination

Moisture, dust, and airborne contaminants present during the brazing process can significantly affect the quality of the resulting joint. The introduction of these impurities into the brazing area may lead to porosity or inclusions within the joint. Such flaws weaken the bond between the base metals and the filler metal, reducing the joint's overall reliability and performance.

Contaminants not only compromise the structural integrity of the joint but also interfere with the proper flow and wetting of the filler metal. When the filler metal cannot flow smoothly over the base materials due to the presence of foreign particles or moisture, the resulting joint is more likely to exhibit weak spots or incomplete bonding.

To minimize the risk of contamination, it is essential to carry out brazing operations in a clean and controlled environment. All components involved in the process should be thoroughly protected from exposure to moisture and particulates at every stage. By maintaining a high standard of cleanliness and consistently safeguarding all parts from contaminants, the quality and durability of the brazed joint can be preserved, ensuring reliable performance in service.

6.4.7 Key Preventive Measures

- Clean and prepare surfaces meticulously.
- Maintain proper joint design and clearance.
- Apply heat evenly and control temperature.
- Use correct filler metal and flux for the application.
- Ensure a clean working environment.

6.5 Influence of Brazing Parameters on the Brazing Result

Brazing parameters are critical in determining the overall quality, strength, and reliability of a brazed joint. Even minor variations in these parameters can result in imperfections or joint failure under operational conditions. The following sections detail the key parameters involved in brazing and describe their effects on the final outcome.

6.5.1 Temperature

The brazing temperature must be carefully selected to ensure it is high enough to melt the filler metal, but not so high that it damages the base materials. If the temperature is too low, the filler metal may not melt completely, resulting in poor wetting and weak joints. Conversely, if the temperature is too high, it can cause excessive oxidation, promote grain growth, and lead to distortion of the base metals. The optimal approach is to adhere to the recommended temperature range for the chosen filler alloy and maintain uniform heating throughout the process.

6.5.2 Heating Rate

The rate at which heat is applied has a direct impact on the integrity of the joint. Rapid heating can introduce thermal shock and cause uneven temperature distribution, which may compromise joint quality. On the other hand, heating too slowly can result in prolonged exposure to elevated temperatures, leading to oxidation and decreased effectiveness of the flux. The best practice is to ensure controlled, uniform heating that minimizes thermal stresses on the materials.

6.5.3 Joint Clearance

Clearance between the parts to be joined is crucial for effective capillary action and filler metal flow. If the clearance is too wide, capillary action is diminished, leading to voids and weak joints. If the clearance is too narrow, the flow of filler metal may be restricted, causing incomplete penetration. Maintaining the recommended clearance, typically between 0.05 and 0.15 mm, is essential for optimal results.

6.5.4 Atmosphere

The surrounding atmosphere during brazing plays a significant role in oxidation and joint cleanliness. An oxidizing atmosphere can lead to the formation of oxides, which hinder wetting and bonding. In contrast, a protective atmosphere—such as inert gas or vacuum—helps promote clean joints and strong bonds. Utilizing flux or controlled atmospheres is important for preventing oxidation during the brazing process.

6.5.5 Flux Application

Flux serves to prevent oxidation and promote wetting of the filler metal. Insufficient flux application can result in the formation of oxides and poor filler flow, while excessive flux may leave residues that require extensive cleaning after brazing. Applying the correct type and amount of flux evenly is necessary to achieve high-quality joints.

6.5.6 Time at Brazing Temperature

The duration for which the assembly is held at brazing temperature affects both filler distribution and joint quality. If the holding time is too short, there may be incomplete flow and bonding. If it is too long, issues such as grain growth, erosion of the base metal, and breakdown of the flux can occur. It is important to maintain sufficient time for complete filler flow without overheating the components.

7 Fuel Gases and Oxidants: Hazards, Risks, and Safety Measures in Brazing

Fuel and gas oxidant mixtures present a substantial risk in brazing operations due to their explosive and fire hazard potential. When these mixtures are not properly managed, they can ignite spontaneously under certain conditions such as exposure to heat, sparks, or open flames. The combination of combustible gases and oxidizing agents creates an environment where rapid combustion can occur, resulting in severe property damage and potential injury to personnel. To mitigate these dangers, strict adherence to safety protocols is essential, including proper storage, handling, and continuous monitoring of gas systems. Critical preventive measures include leak detection, adequate ventilation, and the installation of flashback arrestors to ensure safe operation.

7.1 Common Gases Used in Brazing

Brazing processes typically utilize a combination of fuel gases and an oxidant—most often oxygen or compressed air—to achieve the necessary heat for the operation. The most frequently used fuel gases are outlined below, each with their specific hazards and associated risks.

7.1.1.1 Acetylene (C_2H_2)

Acetylene is highly flammable and forms explosive mixtures with both air and oxygen. It is sensitive to pressure and can decompose violently if stored above 1.5 bar without proper stabilizers. The primary risks include flashback and backfire incidents, especially if the equipment does not have appropriate safety devices. Any leaks may result in rapid ignition and potential explosions.

7.1.1.2 Propane (C_3H_8) and Butane (C_4H_{10})

Propane and butane are both highly flammable liquefied petroleum gases (LPG). Because they are heavier than air, they tend to accumulate in low-lying areas, which increases the risk of explosion. In confined spaces, leaks can create oxygen-deficient atmospheres and highly explosive conditions.

7.1.1.3 Natural Gas (Methane, CH_4)

Methane, commonly used for large-scale heating applications, is flammable and explosive when mixed with air in concentrations ranging from 5% to 15%. Its leaks are often invisible, which can cause delayed ignition and severe explosions.

7.1.1.4 Hydrogen (H_2)

Hydrogen is extremely flammable and burns with an almost invisible flame, making detection particularly challenging. Its high diffusion rate increases the likelihood of leaks, and it easily forms explosive mixtures with air.

7.1.1.5 Other Gases

Other gases, such as ethylene, ethane, and MPS mixtures (methylacetylene-propadiene), may also be used in brazing, depending on the specific application. Each of these requires careful management and is typically mixed with oxygen or compressed air in precise ratios to achieve the desired flame characteristics. For instance, acetylene usually requires a near-neutral flame with a ratio of about 1:1.1 fuel gas to oxygen, while propane generally uses a ratio of approximately 1:3.75.

7.1.2 General Hazards and Risks Associated with Fuel Gases

All fuel gases, when combined with oxygen or air, can create highly explosive conditions—particularly if backflow occurs in hoses or regulators. Flashback hazards are significant, as flames traveling back into the equipment can ignite mixed gases internally, potentially causing catastrophic equipment failure. Furthermore, incorrect pressure settings can destabilize flames and increase the risk of gas leaks, thereby compounding the hazards present in the work environment.

7.1.3 Preventive Measures

To ensure operational safety, it is crucial to implement several preventive measures. These include the installation of flashback arrestors, non-return valves, and pressure relief devices in accordance with ISO 5175 standards. Additionally, continuous leak detection and proper ventilation are essential components of a comprehensive safety protocol.

7.2 Hoses and Non-Return Valves: Hazards, Risks, and Safety Measures

7.2.1 Hoses: Hazards and Risks

Hoses used in fuel gas and oxygen supply systems are subject to several hazards that can compromise safety during brazing and welding operations. Damaged or worn hoses may develop leaks or allow gas permeation, which can result in the release of fuel gases or oxygen into the work area. This creates the potential for explosive mixtures to form, posing a significant danger to personnel and property. Additionally, hoses that are degraded or subjected to incorrect pressure settings are at risk of bursting under pressure. Such ruptures can cause the sudden release of large volumes of gas, dramatically increasing the risk of fire or explosion. Another critical hazard involves the backflow of gases. If hoses are incorrectly connected or if pressure imbalances arise, oxygen may flow into fuel gas hoses, or fuel gas may enter oxygen hoses. This can lead to the formation of hazardous mixtures inside the hose, which are highly explosive.

7.2.2 Non-Return Valves: Hazards and Risks

Non-return valves play a crucial role in preventing the reverse flow of gases within the system. Without these valves, there is a risk of backflow during pressure fluctuations or improper shutdown

procedures. In such cases, oxygen and fuel gas can mix within hoses or regulators, producing a highly explosive environment. Furthermore, the absence of non-return valves increases the risk of flashback propagation. A flashback occurs when a flame travels backward through the hose; without non-return valves, the flame can reach regulators or cylinders, potentially resulting in catastrophic system failure.

7.2.3 Safety Measures

To address these hazards and risks, specific safety measures must be implemented. The use of non-return valves is essential and should be installed at hose connections to prevent the reverse flow of gases. These devices are a mandatory requirement according to ISO 5175 standards for welding and brazing equipment. For comprehensive protection, non-return valves should be combined with flashback arrestors, which are designed to stop flames from traveling back into hoses and other equipment. Regular inspection of hoses is necessary to identify cracks, wear, or leaks, and any damaged hoses should be replaced immediately. Correct hose color coding and proper connections, following ISO standards (such as red hoses for fuel gas and blue hoses for oxygen), are important to prevent cross-connection errors. Lastly, it is vital to maintain proper operating pressures to minimize stress on hoses and reduce the likelihood of backflow conditions.

7.3 Ventilation and Fume Hazards

7.3.1 Hazards and Risks from Fumes

Brazing processes can expose workers to several hazardous fumes and gases. Filler metals used in brazing may contain toxic elements such as zinc, cadmium, or lead. When these metals are heated, they emit fumes that can irritate the respiratory system, cause metal fume fever, and, with prolonged exposure, result in serious health concerns like kidney damage or cancer.

In addition to metal fumes, the fluxes employed during brazing may produce vapors containing fluorides or borates. These vapors can irritate the eyes, skin, and lungs of workers in the area.

Another risk arises from the incomplete combustion of fuel gases such as acetylene, propane, or natural gas. This process can generate carbon monoxide (CO), a colorless and odorless gas that is highly toxic and can cause asphyxiation if allowed to accumulate.

Poor ventilation further increases hazards by reducing oxygen levels in the work environment. In confined or inadequately ventilated spaces, this oxygen depletion can lead to symptoms ranging from dizziness and unconsciousness to potentially fatal outcomes.

7.3.2 Safety Measures

To mitigate these risks, it is essential to ensure adequate ventilation in the work area. This can be achieved through the use of local exhaust systems or general ventilation arrangements to effectively remove fumes and maintain a safe level of oxygen.



Fume extraction systems, such as extraction hoods or portable fume collectors, should be installed close to the brazing operation to capture hazardous fumes directly at their source.

When ventilation alone is insufficient to control exposure, workers should use personal protective equipment (PPE), specifically respirators that are approved for protection against metal fumes and chemical vapors.

Regular monitoring of air quality is necessary to detect the presence of carbon monoxide and other hazardous gases, especially in enclosed or poorly ventilated environments.

Additionally, handling fluxes properly by storing and applying them in accordance with manufacturer guidelines can help minimize the release of harmful vapors

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