JOINING

UNDERSTANDING THE BASICS

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Preface

This book is a rather brief introduction to industrial joining processes. The intent was to take an extensive amount of technical information on the individual joining processes and boil it down to provide a readable resource on joining. The majority of the information in this book was extracted from the *ASM Handbook* series. The book covers all of the major welding processes; brazing and soldering; mechanical fastening; and adhesive bonding.

Welding is a process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the workpieces and adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld. No other technique is as widely used as welding to join metals and alloys efficiently and to add value to their products. Most of the familiar objects in modern society, from buildings and bridges, to vehicles, computers, and medical devices, could not be produced without the use of welding.

Until the end of the 19th century, the only welding process was forge welding, which blacksmiths had used for centuries to join iron and steel by heating and hammering them. Arc welding and oxyfuel welding were among the first processes to develop late in the century, and resistance welding followed soon after. Welding technology advanced quickly during the early 20th century as World War I and World War II drove the demand for reliable and inexpensive joining methods. Following the wars, several modern welding techniques were developed, including manual methods like shielded metal arc welding, now one of the most popular welding methods; as well as semiautomatic and automatic processes such as gas metal arc welding, submerged arc welding, flux-cored arc welding and electroslag welding. Developments continued with the invention of laser beam welding and electron beam welding in the latter half of the century. Today, the science continues to advance. Robot welding is becoming more commonplace in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality and properties. Welding today is applied to a wide range of materials and products, using such advanced technologies as lasers and plasma arcs.

After an introduction to the various joining processes (Chapter 1), the next five chapters address different welding processes. It is estimated that 90% of all industrial welding is done by arc welding The arc welding processes covered in Chapter 2 include shielded metal arc welding, flux-cored arc welding, submerged arc welding, gas metal arc welding, gas tungsten arc welding, plasma arc welding, plasma-MIG welding, and electroslag welding and electrogas welding.

Resistance welding is a group of processes in which the heat for welding is generated by the resistance to the flow of an electrical current through the parts being joined. It is most commonly used to weld two overlapping sheets or plates that may have different thicknesses. Specific resistance welding processes covered in Chapter 3 include resistance spot welding, resistance seam welding, projection welding, flash welding, and upset welding.

The other fusion welding processes that were not covered in Chapters 2 and 3 are covered in Chapter 4. These include oxyfuel gas welding, oxyacetylene braze welding, stud welding (stud arc welding and capacitor discharge stud welding), high-frequency induction welding, electron beam welding, laser beam welding, and thermite welding.

Some of the metallurgical variables in fusion welding are reviewed in Chapter 5. These include energy intensity, heat flow, weld pool solidification, solid-state transformations after solidification, residual stresses and distortion, distortion control, welding discontinuities, weld cracking, fatigue strength of weldments, and inspection of welded joints.

Solid-state welding processes (Chapter 6) are those that produce coalescence of the faying surfaces at temperatures below the melting point of the base metal being joined without the addition of brazing or solder filler metal. Pressure may or may not be applied. These processes involve either the use of deformation or of diffusion and limited deformation in order to produce high-quality joints between both similar and dissimilar materials. Specific solid-state welding processes include: diffusion bonding, forge welding, roll welding, coextrusion welding, cold welding, friction welding and friction stir welding, explosive welding, and ultrasonic welding.

Brazing and soldering processes, covered in Chapter 7, use a molten filler metal to wet the mating surfaces of a joint, with or without the aid of a fluxing agent, leading to the formation of a metallurgical bond between the filler and the respective components. Solders usually react to form intermetallic phases, that is, compounds of the constituent elements that have different atomic arrangements from the elements in solid form. By contrast, most brazes form solid solutions, which are mixtures of the constituents on an atomic scale. Joining processes of this type are defined as soldering if the filler melts below 450 °C (840 °F) and as brazing if it melts above this temperature.

A mechanical fastener is a hardware device that mechanically joins or affixes two or more objects together. The concept of the screw was described by the Greek mathematician Archytas of Tarentum (428-350 BC). Mechanical fastening is the subject of Chapter 8. One unique feature of mechanical fastening is that the joint can either be permanent (e.g., riveting) or temporary (e.g., screws). Many types of fasteners and fastening systems have been developed for specific requirements, such as high strength, easy maintenance, corrosion resistance, reliability at high or low temperatures, or low material and manufacturing costs. Fastener types discussed include threaded fasteners (bolts and screws), pin and collar fasteners, rivets, blind fasteners, and miscellaneous fastening methods such as stitching, stapling, snap fits, and integral fasteners.

An adhesive (Chapter 9) is a polymeric mixture in a liquid or semiliquid state that adheres or bonds items together. Adhesives may come from either natural or synthetic sources. The types of materials that can be bonded are vast but they are especially useful for bonding thin materials. Adhesives cure (harden) by either evaporating a solvent or by chemical reactions that occur between two or more constituents. Adhesives are advantageous for joining thin or dissimilar materials, minimizing weight, and when a vibration dampening joint is needed.

While adhesive bonding is often thought of as a relatively new technology, the oldest known adhesive, dated to approximately 200,000 BC, is from spear stone flakes glued to a wood with birch-bark-tar, which was found in central Italy. The use of compound glues to attach stone spears into wood dates back to round 70,000 BC. Evidence for this has been found in Sibudu Cave, South Africa and the compound glues used were made from plant gum and red ochre. The Tyrolean Iceman had weapons fixed together with the aid of glue.

A number of materials and material combinations are difficult to join, either because of their individual chemical compositions or because of large differences in physical properties between the two materials being joined. In any dissimilar joining process high temperatures, differences in the coefficients of thermal expansion (CTEs) are a major consideration. In Chapter 10, a number of these situations are covered: welding of dissimilar metal combinations; joining of plastics by mechanical fastening, solvent and adhesive bonding, and welding; joining of thermoset and thermoplastic composite materials by mechanical fastening, adhesive bonding, and for thermoplastic composites, welding; the making of glass-to-metal seals; and joining of oxide and nonoxide ceramics to themselves and to metals by solid-state processes and by brazing.

This book is intended for those wishing to learn more about the technology of joining of materials. It would be useful to almost anyone who is interested in or deals with joining, including designers, structural engineers, material and process engineers, manufacturing engineers, managers, and students and faculty. It is brief enough to serve as a first text on joining that can later be supplemented by more advanced texts.

I would like to acknowledge the help and guidance Eileen De Guire of ASM, the editorial staff at ASM, and the people that reviewed this manuscript for their valuable contributions.

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CHAPTER 1

Introduction to Joining

JOINING COMPRISES a large number of processes used to assemble individual parts into a larger, more complex component or assembly. The individual parts of a component meet at the *joints*. Joints transmit or distribute forces generated during service from one part to the other parts of the assembly. A joint can be either temporary or permanent. The five joint types that are predominately used in the joining of parts are the butt, tee, corner, lap, and edge joints (Fig. 1.1).

The selection of an appropriate design to join parts is based on several considerations related to both the product and the joining process. Product-related considerations include codes and standards, fitness for service, aesthetics, manufacturability, repairability, reliability, inspectability, safety, and unit cost of fabrication. Joining process considerations include material types and thicknesses, joint geometry, joint location and accessibility, handling, jigging and fixturing, distortion control, productivity, and initial and recurring manufacturing costs. Additional considerations in-

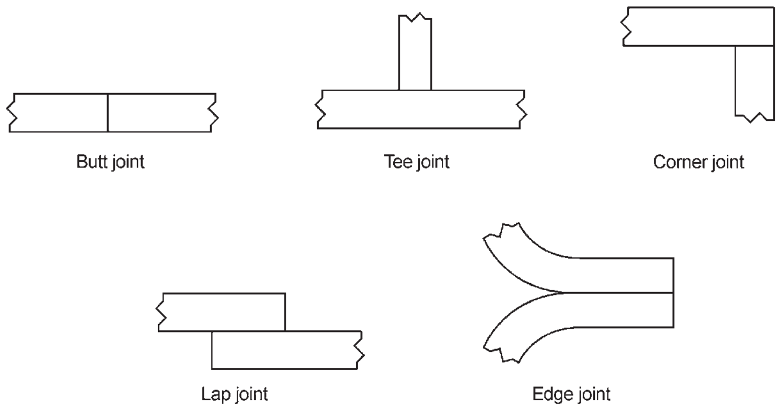


Fig. 1.1 Types of joints. Source: Ref 1.1

clude whether the joint is fabricated in a shop or at a remote site, possibilities for failure, and containment in case of a catastrophic failure (e.g., a nuclear reactor vessel).

The design or selection of appropriate joint type is determined primarily by the type of service loading the assembly will be exposed to during its service life. For example, in metallic structures, butt joints are preferred over tee, corner, lap, or edge joints for components subjected to fatigue loading, while a lap joint would be optimum for an adhesive-bonded structure. However, since high-strength adhesives are typically weak in peel, the lap joint should be loaded in shear. To effectively transfer loads through the adhesive, the substrates (or adherends) are overlapped so that the adhesive is loaded in shear. Typical adhesive-bonded joint designs are shown in Fig. 1.2. The specific joint design aspects, such as the size, length, and relative orientation of the joint, are based on stress calculations that are results of the anticipated service loads, properties of materials, properties of sections, and appropriate structural design requirements. An ideal joint is one that effectively transmits forces among the joint members and throughout the assembly, meets all structural design requirements, and can still be produced at a minimal cost. This involves selection and application of good design practices based on a thorough understanding of the available joining processes.

Assembly imposes constraints on the design. The parts must be designed so that they not only can be assembled and joined together to provide the needed function but also are easy to handle, insert, retain, and verify that they have been assembled correctly. Because assembly is an integrative process, problems with detail part designs often surface when they are assembled. For example, parts may not fit together properly, tools may not reach in the space provided, and parts may be incorrectly as-

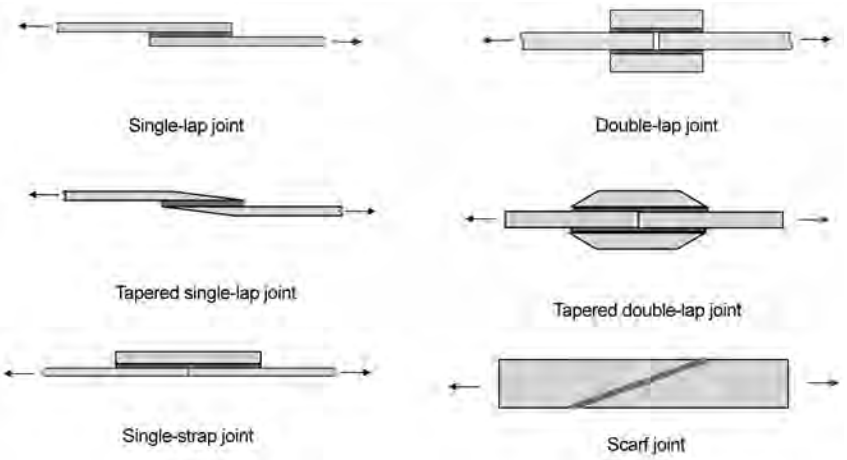


Fig. 1.2 Typical adhesive-bonded joint configurations. Note that the adhesive is loaded in shear in all configurations. Source: Ref 1.2

sembled. These problems often require extensive rework, resulting in costly schedule slippage and undesirable design compromises.

The importance of assembly as a design constraint has resulted in a greatly increased emphasis on assembly in the design process. Design and manufacturing practice now focuses on ensuring that parts conform to specifications and that variability and randomness are minimized, and on making non-value-added operations such as orienting and handling as simple and easy to perform as possible. Many product design departments now improve the ease with which products are assembled by using design for assembly (DFA) techniques, which seek to ensure ease of assembly by developing designs that are easy to assemble.

The aim of DFA is to simplify the product so that the cost of assembly is reduced. However, DFA techniques often result in improved quality and reliability, along with a reduction in production equipment and part inventory. These secondary benefits often outweigh the cost reductions in assembly.

General guidelines for DFA

- Minimize part count by incorporating multiple functions into single parts.
- Modularize multiple parts into single subassemblies.
- Assemble in open space, not in confined spaces; never bury important components.
- Make parts such that it is easy to identify how they should be oriented for insertion.
- Prefer self-locating parts.
- Standardize to reduce part variety.
- Maximize part symmetry.
- Eliminate parts that will tangle.
- Color code parts that are different but shaped similarly.
- Prevent nesting of parts; prefer stacked assemblies.
- Provide orienting features on nonsymmetries.
- Design the mating features for easy insertion.
- Provide alignment features.
- Insert new parts into an assembly from above.
- Eliminate reorientation of both parts and assemblies.
- Eliminate fasteners.
- Place fasteners away from obstructions; design in fastener access.
- Deep channels should be sufficiently wide to provide access to fastening tools; eliminate channels if possible.
- Provide flats for uniform fastening and fastening ease.
- Ensure sufficient space between fasteners and other features for a fastening tool
- Prefer easily handled parts.

Generally, a concept design is developed and then evaluated against each of these guidelines. Design modifications are then made to satisfy the guideline. There is no guarantee that a given guideline will apply to a particular design problem. Many of these guidelines are similar or the same as the rules of concurrent engineering:

Concurrent engineering rules

- Ensure that parts most likely to require maintenance are easily accessible.
- Ensure that the degree of maintenance of your product is consistent with your company's policy on making, stocking, and supplying spare parts.
- Ensure tools needed for installation and maintenance are as inexpensive and common as possible.
- The decisions made in the first 15% of a product development process fix 85% of the downstream quality and cost of the product.
- Include all experts actively.
- Resist making irreversible decisions.
- Continually optimize the designed product *and* the design process.
- Prefer concepts that are easy to manufacture.
- Prefer concepts that are easy to assemble.
- Integrate design and manufacturing.
- Do not overconstrain or underconstrain the design.
- Look ahead of the current state of the design to anticipate problems.
- Reduce the number of parts.
- Increase interchangeability of parts; standardize parts; minimize variation in parts.
- Modularize functions and subassemblies.
- Design multifunctional and multiple-use parts.
- Avoid flexible components.
- Avoid separate fasteners.
- Improve robustness.
- Allocate time/man power based on cost-benefit analysis of a proposed action.
- Maximize yield of existing equipment.
- Keep assemblies/components as independent as possible.
- Maximize tolerances.
- Test only what can be quantified; actively search for testable aspects of a design.
- Minimize machining setups and reorientations.
- Design parts for feeding and insertion into machines.
- Perform functional analysis.
- Tailor the manufacturing process to the character of the product.
- Study producibility and usability.
- Design the fabrication process.

- Design the assembly sequence for top-down assembly.
- Minimize assembly instructions.
- Use known/proven vendors and suppliers.
- Use new technologies only when necessary.
- Identify subassemblies as soon as possible in the design process.
- Do engineering changes in batches.
- Integrate quality control with assembly.
- Match assembly processes to tolerances.
- Operate on a minimum inventory.

While some of these guidelines and rules may not always be applicable, and even occasionally contradict each other, they are certainly worth considering during the design process.

1.1 Overview of Joining Processes

Joining processes include welding, brazing, soldering, mechanical fastening, and adhesive bonding (Fig. 1.2). Mechanical fastening can be used to provide either temporary or permanent joints, while adhesive bonding, welding, brazing, and soldering processes are mainly used to provide permanent joints. Mechanical fastening and adhesive bonding usually do not cause metallurgical reactions. Consequently, these methods are often preferred when joining dissimilar combinations of materials and for joining polymer-matrix composites that are sensitive to extreme heat. Welding processes are divided into two broad classes: fusion welding and solid-state welding.

1.2 Fusion Welding

Fusion welding processes involve localized melting and solidification and are normally used when joining similar material combinations or materials belonging to the same family (e.g., joining one type of stainless steel with another type). In fusion welding, the weld can be made by simply melting the edges of the two workpieces and allowing them to fuse together on cooling. This type of weld is referred to as an *autogenous weld*. The other method is to add extra material during the welding process through the melting of an electrode or filler wire during the welding process. In both cases, the welded area will have a microstructure and properties that are different from the parent metal. The three predominant zones in a fusion weld are the fusion zone, a heat-affected zone (HAZ), and the base metal as shown in Fig. 1.3. The weld deposit itself will have a cast structure of often a complex composition. Between the weld deposit and the parent metal is an HAZ that did not melt during welding but reached very high temperatures. Grain growth due to the high temperatures is commonly encountered in the HAZ.

The types of welds commonly used with fusion welding processes are shown in Fig. 1.4. Joint designs and clearances that overwhelmingly trap the beam energy within the joint cavity are preferred for increased process efficiency. When joining thick sections, the preferred joint designs allow the weld metal to freely shrink without causing cracking. In addition, multipass welding is used for thick sections to provide for full penetration. The distinctive microstructure of a multipass weld compared to a single-pass weld is shown in Fig. 1.5. To maintain tolerances, distortion due to localized heating and cooling must be prevented or controlled during welding by the use of jigs and fixtures. Residual stresses can lead to distortion after welding and are often minimized by a stress-relief anneal after welding.

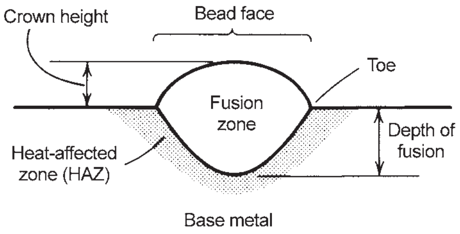


Fig. 1.3 Weld bead geometry showing fusion zone, heat-affected zone, and base metal. Source: Ref 1.3

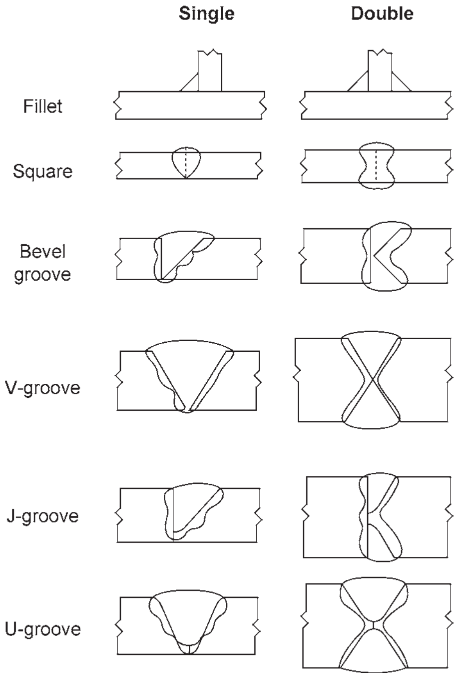


Fig. 1.4 Types of welds. Source: Ref 1.1

Thermal Welding. Heat is provided by an oxyfuel gas flame, mostly for manual welding, or by a thermit reaction for joining heavy sections such as rails. Portability is a great advantage.

Electric Arc Welding. Electric arc welding processes use electricity to produce the intense heat necessary for welding (Fig. 1.6). Some electric arc processes use a consumable electrode that melts and becomes part of the weld metal that is deposited, whereas others use a nonconsumable electrode that does not melt and does not become part of the weld deposit. Consumable electrode welding uses a filler rod as the electrode. Atmospheric protection of the molten weld metal is provided by a slag produced by the filler rod or by an externally supplied inert gas. Flux-cored wire allows a continuous and mechanized operation. The flux is supplied as a powder in submerged arc welding for horizontal welds, and a resistive slag pool protects the weld zone in electroslag welding of thick plates. Inert gas provides the protection in some welding processes, such as gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW).

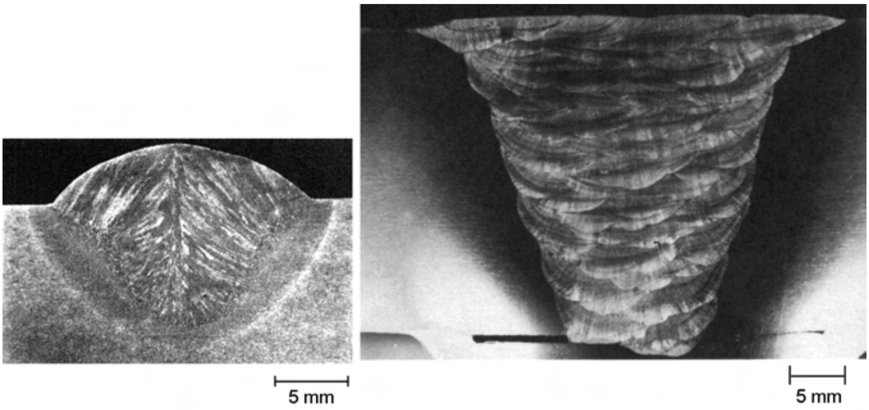


Fig. 1.5 Weld microstructures showing the fusion zone, heat-affected zone, and base metal for (a) single-pass bead-on-plate weld in A-710 steel and (b) multipass weld in 304 stainless steel. Source: Ref 1.3

Fig. 1.6 Welding using shielded metal arc welding process

Resistance Welding. After the two parts have been pressed together, electric current passes through the joint to heat and melt the interface. Pressure is kept on until solidification of the melt is complete. Spot welding is widely employed in building automotive bodies using welding robots. Seam welding, a continuous stream of spot welds, is used for making beams and box sections.

High-Energy Beam Welding. Highly concentrated beams of electrons impinge on the weld zone in electron beam (EB) welding. When the workpiece is enclosed with the gun in a vacuum chamber, a high vacuum protects the surfaces but increases cost and lowers production rates. Out-of-chamber welding is also possible. Gas (CO_2) or solid-state (Nd-YAG) lasers have seen increasing application for joining not only difficult metals and delicate parts but also sheets of different thicknesses for tailored blanks used in automobile body construction. All high-energy beam processes have the advantage that the HAZ is small, as shown in the EB weld microstructure in Fig. 1.7.

1.3 Solid-State Welding

Since solid-state welding processes do not involve melting and solidification, they are often suitable for joining not only similar but also dissimilar materials. Solid-state welding processes also have special joint design or part cross-section requirements. For example, continuous drive and inertia friction welding processes require that one of the parts exhibit a circular or near-circular cross section.

Diffusion bonding is a solid-state welding process that allows joining of a variety of structural materials, both metals and nonmetals. However, diffusion bonding requires an extremely smooth surface finish to provide intimate surface contact, a high temperature, and a high pressure, first to

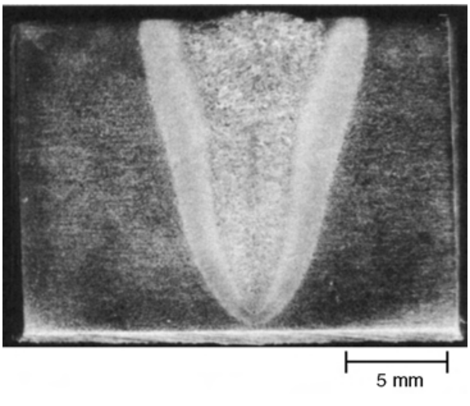


Fig. 1.7 25Cr-1Mo steel plate, single-pass electron beam weld. Macrostructure shows high depth-to-width ratio of the fusion zone, which is typical of high-energy-density welding processes. Source: Ref 1.3

allow intimate contact of the parts along the bond interface, followed by plastic deformation of the microscopic surface asperities, and then to promote diffusion across the bond interface. The need to apply pressure while maintaining part alignment imposes a severe limitation on joint design. When perfectly clean surfaces are brought into intimate contact, interatomic bonds form a joint. Bond strength is greatest when the mating metals are mutually soluble, but good bonds can be obtained with dissimilar, not otherwise weldable metals and with highly differing thicknesses. When an exceptional surface finish is difficult to achieve, a metallurgically compatible, low-melting interlayer can be inserted between the parts to produce a transient liquid phase on heating. On subsequent cooling this liquid phase undergoes progressive solidification, aided by diffusion across the solid/liquid interfaces, and thereby joins the parts. This process is similar to a brazing process.

Cold Welding. Sufficient pressure must be exerted to establish conformance of surfaces. Sliding and deformation accompanied by surface expansion are needed to break up oxides and other adsorbed films. Cold welding processes differ only in the method of providing these conditions. Complex tubular parts such as refrigerator evaporator plates can be made by depositing a parting agent in a pattern to prevent welding. After roll bonding the passages may be inflated.

Forge Welding. As a generic term, forge welding applies to bonding by deformation at the hot-working temperature. Large surface extension in hot-roll bonding creates strong bonds for cladding, as in bonding copper-nickel surface layers to a copper core for some U.S. coins.

Friction Welding. Heat is produced by friction between a rotating and stationary part; again, some melt may form that is expelled together with oxidized metal. Localization of heat allows welding of dissimilar metals and of very different dimensions (e.g., a thin stem to a large head for an internal combustion engine valve).

From a metallurgical perspective, the application of both fusion welding and solid-state welding processes must be evaluated using appropriate weldability test methods for their ability to either recreate or retain base metal characteristics across the joint. When metallurgical reactions occur, they can either benefit or adversely affect the properties of the joint. These weldability evaluations need to combine material, process, and procedure aspects to identify combinations that would provide a weld joint with an acceptable set of properties.

1.4 Brazing

Brazing is a process for joining solid metals in close proximity by introducing a liquid metal that melts above 450 °C (840 °F). A sound brazed joint generally results when an appropriate filler alloy is selected, the parent metal surfaces are clean and remain clean during heating to the flow temperature of the brazing alloy, and a suitable joint design is used that allows capillary action. Strong, uniform, leak-proof joints can be made rapidly, inexpensively, and even simultaneously. Joints that are inaccessible and parts that may not be joinable at all by other methods can often be joined by brazing. Complicated assemblies comprising thick and thin sections, odd shapes, and differing wrought and cast alloys can be turned into integral components by a single trip through a brazing furnace or a dip pot. Metal as thin as 0.01 mm (0.0004 in.) and as thick as 150 mm (6 in.) can be brazed.

Brazed joint strength is high. The nature of the interatomic (metallic) bond is such that even a simple joint, when properly designed and made, will have strength equal to or greater than that of the parent metal. The fact that brazing does not involve any substantial melting of the base metals offers several advantages over other welding processes. It is generally possible to maintain closer assembly tolerances and to produce a cosmetically neater joint without costly secondary operations. Even more important is that brazing can join dissimilar metals (or metals to ceramics) that, because of metallurgical incompatibilities, cannot be joined by traditional fusion welding processes. If the base metals do not have to be melted to be joined, it does not matter that they have widely different melting points. Therefore, steel can be brazed to copper as easily as to another steel. Brazing also generally produces less thermally induced distortion, or warping, than does fusion welding. An entire part can be brought up to the same brazing temperature, thereby preventing the kind of localized heating that causes distortion in welding.

Finally, and perhaps most important to the manufacturing engineer, brazing readily lends itself to mass production techniques. It is relatively easy to automate because the application of heat does not have to be localized, as in fusion welding, and the application of filler metal is less critical. In fact, given the proper clearance conditions and heat, a brazed joint is not dependent on operator skill, as are most fusion welding processes. Automation is also simplified by the fact that heat can be applied to the joint by many means, including torches, furnaces, induction coils, electrical resistance, and dipping. Several joints in one assembly often can be produced in one multiple-braze operation during one heating cycle, further enhancing production automation.

1.5 Soldering

Soldiering is a joining process by which two substrates are joined together using a filler metal (solder) with a liquidus ≤450 °C (≤840 °F). The substrate materials remain solid during the bonding process. The solder is usually distributed between the properly fitted surfaces of the joint by capillary action.

The bond between solder and base metal is more than adhesion or mechanical attachment, although these do contribute to bond strength. Rather, the essential feature of the soldered joint is that a metallurgical bond is produced at the interface between the filler metal and base metal. The solder reacts with the base metal surface and wets the metal by intermetallic compound formation. Upon solidification, the joint is held together by the same attraction, between adjacent atoms, that holds a piece of solid metal together. When the joint is completely solidified, diffusion between the base metal and soldered joint continues until the completed part is cooled to room temperature. Therefore, the mechanical properties of soldered joints are generally related to, but not equivalent to, the mechanical properties of the soldering alloy.

Mass soldering by wave, drag, or dip machines has been a preferred method for making high-quality, reliable connections for many decades. Correctly controlled, soldering is one of the least expensive methods for fabricating electrical connections.

1.6 Mechanical Fastening

The primary function of a fastener system is to transfer load. Many types of fasteners and fastening systems have been developed for specific requirements, such as high strength, easy maintenance, corrosion resistance, reliability at high or low temperatures, or low material and manufacturing costs. The selection and satisfactory use of a particular fastener are dictated by the design requirements and conditions under which the fastener will be used. Consideration must be given to the purpose of the fastener, the type and thickness of materials to be joined, the configuration and total thickness of the joint to be fastened, the operating environment of the installed fastener, and the type of loading to which the fastener will be subjected in service. A careful analysis of these requirements is necessary before a satisfactory fastener can be selected.

The selection of the correct fastener or fastener system may simply involve satisfying a requirement for strength (static or fatigue) or for corrosion resistance. On the other hand, selection may be dictated by a complex system of specification and qualification controls. The extent and complexity of the system needed are usually dictated by the probable cost of a fastener failure. Adequate testing is the most practical method of guarding against failure of a new fastener system for a critical application. The designer must not extrapolate existing data to a different size of the same fastener, because larger-diameter fasteners have significantly lower fatigue endurance limits than do smaller-diameter fasteners made from the same material and using the same manufacturing techniques and joint system.

Mechanical fasteners are grouped into threaded fasteners, rivets, blind fasteners, pin fasteners, special-purpose fasteners, and fasteners for composites. Rivets, pin fasteners, and special purpose fasteners are usually designed for permanent or semipermanent installation. Threaded fasteners are considered to be any threaded part that, after assembly of the joint, may be removed without damage to the fastener or to the members being joined. Rivets are permanent one-piece fasteners that are installed by mechanically upsetting one end. Blind fasteners are usually multiple-piece devices that can be installed in a joint that is accessible from only one side. When a blind fastener is being installed, a self-contained mechanism, an explosive, or other device forms an upset on the inaccessible side. Pin fasteners are one-piece fasteners, either solid or tubular, that are used in assemblies in which the load is primarily shear. A malleable collar is sometimes swaged or formed on the pin to secure the joint. Special-purpose fasteners, many of which are proprietary, such as retaining rings, latches, slotted springs, and studs, are designed to allow easy, quick removal and replacement and show little or no deterioration with repeated use.

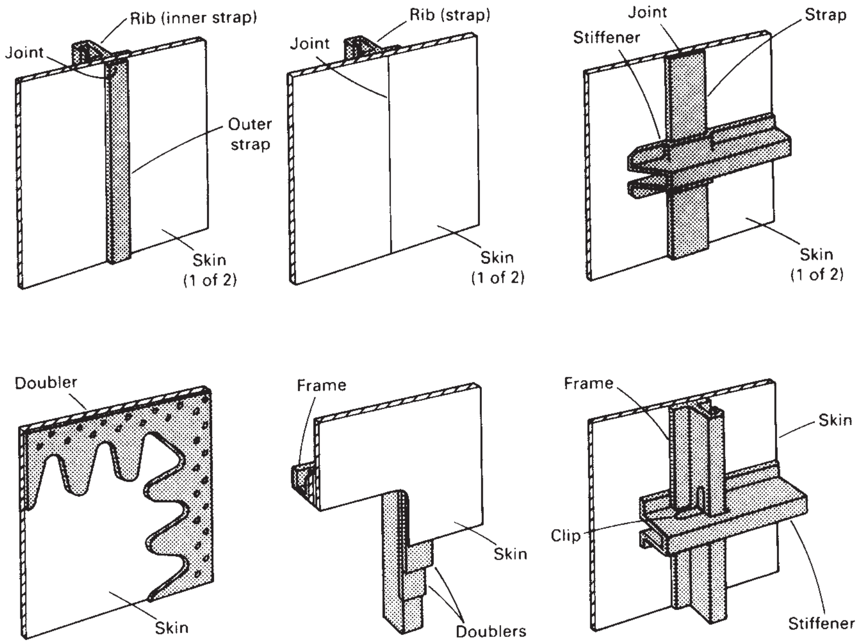
1.7 Adhesive Bonding

Adhesive bonding is a materials joining process in which an adhesive (usually a thermosetting or thermoplastic resin) is placed between the faying surfaces of the parts or bodies called adherends. The adhesive then solidifies or hardens by physical or chemical property changes to produce a bonded joint with useful strength between the adherends.

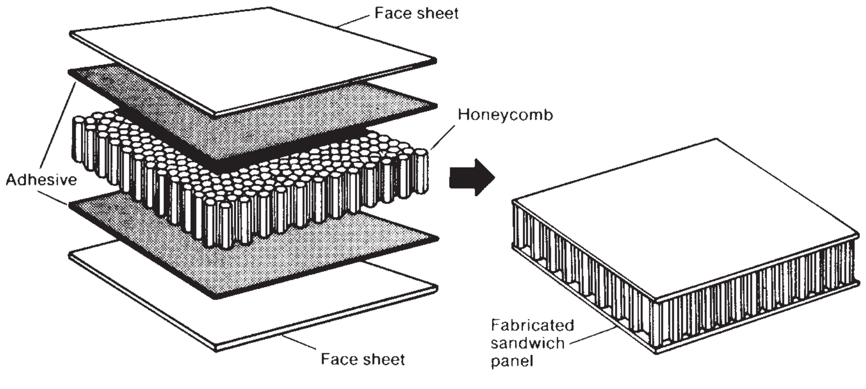
Adhesive-bonded joints are used extensively in aircraft components and assemblies where structural integrity is critical. The structural components are not limited to aircraft applications; they can be translated to commercial and consumer product applications as well. Adhesive bonding is very competitive compared with other joining methods in terms of production cost, ability to accommodate manufacturing tolerances and component complexity, facility and tooling requirements, reliability, and repairability,

Some typical aircraft applications for adhesive bonded structures include:

- Metal-to-metal bonded structures that are locally reinforced by bonded doubler plates or some other type of reinforcement (Fig. 1.8a)
- Metal-to-metal bonded multiple laminations where each layer progressively increases the cross-sectional area of the component (e.g., for stringers and spar caps)
- Bonded joints between rather thin metal sheet and a low-density core material, called honeycomb or sandwich structures (Fig. 1.8b). Core materials include paper dipped in a phenolic resin, fiberglass, aluminum alloy foil, Nomex (aramid fiber paper dipped in phenolic resin), graphite-reinforced plastic, and Kevlar fabric



(a) Adhesive bond joint configurations



(b) Honeycomb bonded assembly

Fig. 1.8 Examples of (a) adhesive bond joint configurations and (b) honeycomb bonded assembly. Source: Ref 1.4

Aluminum alloys that are commonly adhesive bonded include 2024 (T3, T6, and T86), 3*xxx* series alloys, 5052-H39, 5056-H39, and 7075-T6. These alloys may be bonded to themselves, each other, other metals, and many nonmetals, including all forms of paper products, insulation board, wood-particle board, plaster board, plywood, fiberglass, and various polymers and organic matrix composites. Other metals commonly joined by adhesive bonding include Ti-6Al-4V, copper and copper alloys used in microelectronic applications, low-carbon steels, and stainless steels. Successful adhesive bonding of all of these metals requires stringent cleaning procedures, and the cleaned surfaces must be protected from contamination until they are bonded.

Because an adhesive can transmit loads from one member of a joint to another, it allows a more uniform stress distribution than is obtained using mechanical fasteners. Thus, adhesives often permit the fabrication of structures that are mechanically equivalent or superior to conventional assemblies and have cost and weight benefits. For example, adhesives can join thin metal sections to thick sections so that the full strength of the thin section is used. In addition, adhesives can produce joints with high strength, rigidity, and dimensional precision in the light metals, such as aluminum, that may be weakened or distorted by welding.

Because the adhesive in a properly prepared joint provides full contact with mating surfaces, it forms a barrier so that fluids do not attack or soften it. An adhesive may also function as an electrical and/or thermal insulator in a joint. Its thermal insulating efficiency can be increased, if necessary, by forming an adhesive with the appropriate cell structure in place. On the other hand, electrical and thermal conductivity can be raised appreciably by adding metallic fillers. Oxide fillers, such as alumina, increase only thermal conductivity. Electrically conductive adhesives, filled with silver flake, are available with specific resistivities <50 times that of bulk silver.

Adhesives can also prevent electrochemical corrosion in joints between dissimilar metals. They may also act as vibration dampers. The mechanical damping characteristics of an adhesive can be changed by formulation. However, changing such a property in an adhesive generally changes other properties of the joint, such as tensile or shear strength, elongation, or resistance to peel or cleavage. A property somewhat related to the ability to damp vibration is resistance to fatigue. A properly selected adhesive can generally withstand repeated strains induced by cyclic loading without the propagation of failure-producing cracks.

Adhesives usually do not change the contours of the parts they join. Unlike screws, rivets, or bolts, adhesives give little or no visible external evidence of their presence. They are used to join skins to airframes, and they permit the manufacture of airfoils, fuselages, stabilizers, and control surfaces that are smoother than similar conventionally joined structures and that consequently have better aerodynamic efficiency. These structures also have greater load-bearing capability and higher resistance to fatigue than conventionally joined structures.

1.8 Joint Design Considerations

When designing a joint, one should initially consider manufacturability of the joint, whether at a shop or at a remote site. For example, consider the need for a high-integrity, high-performance joint between two dissimilar materials such as a low-carbon steel and an aluminum alloy. If this joint has to be produced at a remote site, the available choice of joining processes is extremely limited. A viable alternative would be to produce at a shop a transition piece involving the two dissimilar materials. Using controlled process conditions at a shop, one could produce a high-integrity transition piece using one of the solid-state welding processes. The selection of the appropriate solid-state welding process would depend on joint (part) geometry. A transition joint between a plate and a pipe is best produced using a friction welding process, whereas a joint between two large plate surfaces is best produced using explosive bonding. Because these joining processes do not involve melting and solidification, they provide high-integrity joints free from porosity or solidification-related defects. Transition pieces so produced could be used at a remote site to make similar metal joints between component parts with no undue quality assurance or quality control concerns.

A joint must be designed to benefit from the inherent advantages of the selected method of joining. For example, braze joints perform very well when subjected to shear loading but not when subjected to pure tensile loading. When using a brazing process to join parts, it would be beneficial to employ innovative design features that would convert a joint subjected to tensile loading to shear loading. For example, the use of single- or double-lap joints (Fig. 1.2) instead of butt joints can provide a beneficial effect in flat parts and tubular sections. Joints should also be designed to reduce stress concentrations. Sharp changes in part geometry near the joint tend to increase stress concentration or notch effects. Smooth contours and radiused corners tend to reduce stress concentration effects. A number of ways to redistribute stresses in a brazed joint are shown in Fig. 1.9.

When determining appropriate joint designs, one should initially consider standard or recommended joint designs. In practice, several standard joint designs may be suitable for producing a joint. Subtle or innovative features could be added to the recommended joint designs to improve productivity through mechanization or automation, to enhance joint performance, and to ensure safety.

Orientation and Alignment. Design features that promote self-location and maintain the relative orientation and alignment of component parts save valuable time during fit-up and enhance the ability to produce a high-quality joint. For example, operations involving furnace brazing or diffusion bonding with interlayers benefit from such a type of joint design, because they allow preplacement of the brazing filler or the interlayer in the joint. The pin-socket type of temporary joints in modern electrical, telephone, and computer connectors allow temporary joining of cables in only one way. These joint designs strongly discourage any inadvertent misalignment or wrong orientation of the connectors and thereby eliminate a variety of hazards. The snap-on interlocking features in twisted, threaded, or nonthreaded adapter joint designs, commonly used in chil-

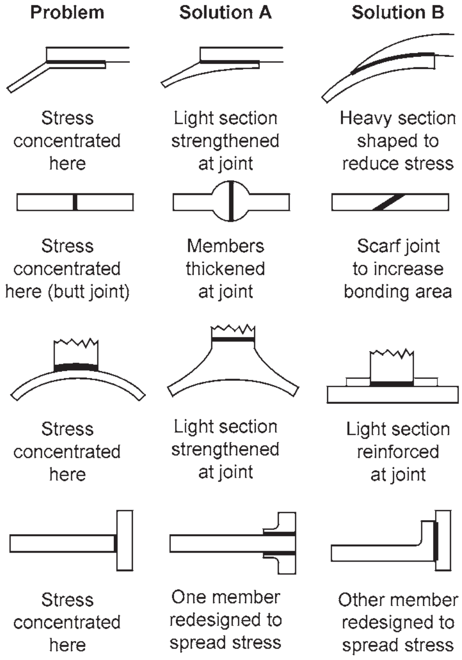


Fig. 1.9 Design of a brazed joint to redistribute stress. Source: Ref 1.1

dren's toys, often allow the snapping sound of a latch to indicate the satisfactory completion of the joint and its safety for the intended use.

Jigging and fixturing can also be used to maintain relative orientation of parts. When necessary, the fixturing devices should be designed for the least possible thermal mass and pinpoint or knife-line contact with the parts. Fixtures of low thermal mass and minimal contact with the parts reduce the overall thermal load during joining. Further, arc welding processes generally allow higher deposition rates when joining is performed in the flat position, where gravity effects tend to support a large volume of molten weld metal at the joint region. When joining parts that exhibit a nonplanar joint contour, positioning equipment can be used to continuously manipulate the parts so that the welding is performed in the flat position. In such cases, the design of the joint and fixtures should be complementary to the positioning equipment used, and it should not interfere with the functioning of the positioning equipment.

Joint Location and Accessibility. From a structural integrity standpoint, joint locations should be chosen such that they are not in regions subjected to maximum stress. Concurrently, joints must be placed in locations that will allow operators to readily make the joints using the selected method of joining. The effect of joint location on accessibility is illustrated in Fig. 1.10. Limited accessibility can reduce the overall quality of the joint, decrease productivity, or both. Invariably, limited accessibility to

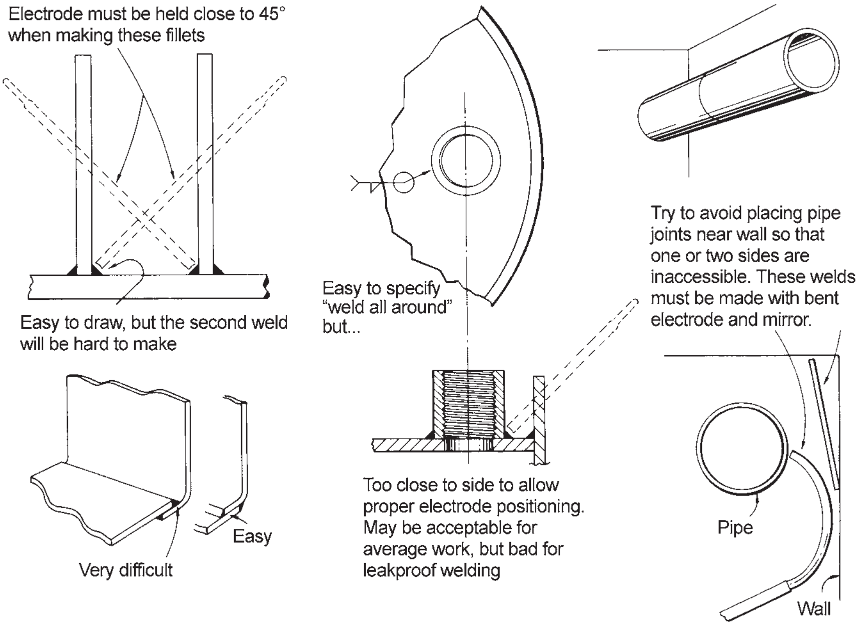


Fig. 1.10 Effect of joint location on accessibility. Source: Ref 1.4

produce joints also limits accessibility to perform nondestructive evaluation of joint quality, either during the time the joint is made or afterward.

Weld joint designs employ bevel angles and root openings to enhance accessibility to the welding torch (or electrode) and provide adequate weld penetration. The best bevel angles provide adequate accessibility while reducing the amount of weld metal required to complete the joint. Currently, computer-based software tools are available to facilitate the selection of a weld joint for minimizing the amount of weld metal. Use of such computer-based selection of joint designs increases welding productivity (joint completion rate), improves quality, and reduces overall fabrication cost, but such designs must be used only when they are consistent with structural design requirements. For this reason, codes such as the ASME Boiler and Pressure Vessel Code, Section IX: Welding and Brazing Qualifications, and ANSI/AWS D1.1 Structural Welding Code Steel provide flexibility to a welding manufacturer (fabricator) to select or change weld joint design for fabrication, but they require the manufacturer to qualify the welding procedure to meet design performance requirements whenever changes are made to a previously qualified, nonstandard weld joint design. In recent years, the use of narrow-gap gas metal arc welding (GMAW) and submerged arc welding techniques in the place of conventional welding techniques for welding thick-section pressure vessel steels has contributed significantly to increased weld joint completion rates.

Unequal Section Thickness. When constituent members of an assembly exhibit unequal section thicknesses, modifications to the recommended joint designs will be necessary for a variety of technical reasons, but mainly to provide a smooth flow of stress patterns through the unequal sections. When making a fillet weld using an arc welding process, if thicknesses of the members are not greatly different, directing the arc toward the thicker member may produce acceptable penetration. However, special designs for joining will be required when the components to be welded exhibit a large heat sink differential (difference in heat-dissipating capacities). When a thick member is joined to a thin member, the welding heat input needed to obtain a good penetration into the thick member is sometimes too much for the thin member and results in undercutting of the thin member and a poor weld. Similarly, if the proper amount of heat for the thin member is used, the heat is insufficient to provide adequate fusion in the thick member, and again, a poor weld results. Too little heat input can also cause underbead cracking in certain structural materials.

A widely applicable method of minimizing heat sink differential is to place a copper backing block against the thin member during fusion welding (Fig. 1.11). The block serves as a chill, or heat sink, for the thin member. The block can be beveled along one edge so that it can be used when horizontal fillet welds are deposited on both sides of a thin member. Copper backing bars or strips are made in a variety of shapes and sizes to dissipate heat as needed. Often some experimentation and proof testing are required to obtain the optimum backing location and design. Another way to obtain equalized heating and smooth transfer of stress where unequal section thicknesses are being welded is to taper one or both members to obtain an equal width or thickness at the joint. Commonly, when two pipes of dissimilar internal diameter and wall thickness are to be joined, a convenient way is to introduce a "reducer" between the two pipes. One end of the reducer will have the same size and wall thickness as the larger pipe, while the other end of the reducer will have the same size and wall thickness as the smaller pipe.

Distortion Control. Design of an appropriate weld joint can also help reduce welding-related distortion. Fusion welding processes employ lo-

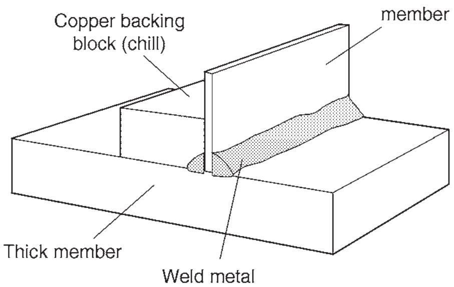


Fig. 1.11 Use of copper backing block as a chill to minimize heat sink differentials. Source: Ref 1.4

calized melting and solidification to join component parts, which can result in excessive thermal strains. These thermal strains depend on the type of material, the welding process, and the welding procedure. Thermal strains produced by fusion welding processes can cause residual stresses and distortion, leading to transverse and angular shrinkage. Reducing the overall length of the weld or the amount of weld metal that needs to be deposited to complete a joint reduces both residual stresses and distortion. For example, intermittent welding instead of continuous welding reduces the overall length of a weld. Similarly, the use of a double-V groove instead of a single-V groove results in the reduction of the amount of weld metal and minimizes transverse shrinkage. Further, the amount of angular shrinkage is strongly influenced by the ratio of the weld metal in the top and the bottom sides of the plate. To minimize the out-of-plane distortion in fillet welded joints, efforts should be directed to using the minimum size of the welds that is consistent with strength considerations.

1.9 Process Selection for Joining

Frequently, several joining processes can be used for a particular job. The major problem is to select the one that is the most suitable in terms of fitness for service and cost. These two factors, however, may not be totally compatible, thus forcing a compromise. Selection of a process can depend on a number of considerations, including the number of components being fabricated, capital equipment costs, joint location, structural mass, and desired performance of the product. The adaptability of the process to the location of the operation or the type of shop, and the experience and abilities of the employees may also have an impact on the final selection.

General guides for selecting a suitable joining process for different types of applications are given in Tables 1.1 and 1.2. These tables should be regarded as only general guidance. Additional resources should be consulted for specific applications before final decisions are made or recommended.

Table 1.1 Comparison of joining process characteristics

Attribute	Welding	Brazing and soldering	Mechanical fastening	Adhesive bonding
Performance	Permanent joints	Usually permanent (soldering may be nonpermanent)	Threaded fasteners permit disassembly	Permanent joints
Stress distribution	Local stress points in structure	Fairly good stress distribution	Points of high stress at fasteners	Good uniform load distribution over joint area (except in peel)
Appearance	Joint appearance usually acceptable. Some dressing necessary for smooth surfaces	Good joint appearance	Surface discontinuities sometimes unacceptable	No surface marking. Joint almost invisible

(continued)

Abbreviations: CTE, coefficient of thermal expansion; NDT, nondestructive testing. Source: Ref 1.5

Table 1.1 (continued)

Attribute	Welding	Brazing and soldering	Mechanical fastening	Adhesive bonding
Materials joined	Generally limited to similar material groups	Some capability for joining dissimilar materials	Most forms and materials can be fastened	Ideal for joining most dissimilar materials. CTE difference a concern for elevated temperature bonds
Temperature resistance	Very high temperature resistance	Temperature resistance limited by filler metal	High temperature resistance	Poor resistance to elevated temperatures
Mechanical resistance	Special provisions often necessary to enhance fatigue resistance	Fairly good resistance to vibration	Special provisions for fatigue and resistance to loosening at joints	Excellent fatigue properties. Electrical isolation reduces corrosion.
Joint preparation	Little or none on thin material. Edge preparation for thick plates	Prefluxing usually required	Hole preparation and tapping for threaded fasteners	Stringent cleaning required
Postprocessing	Heat treatment sometimes necessary	Corrosive fluxes must be cleaned off	Usually none. Occasionally retightening in service	Not usually required
Equipment	Relatively expensive, bulky, heavy power supply often required	Manual equipment cheap. Special furnaces and automatic equipment expensive	Relatively cheap and portable for manual assembly. Automated equipment can be expensive.	Can be relatively cheap or expensive for tooling and presses or autoclaves
Consumables	Wire, rods fairly cheap	Some braze alloys expensive. Soft solders cheap	Quite expensive	Structural adhesives somewhat expensive
Production rate	Can be very fast	Automatic processes quite fast	Manual processes slow. Automated processes can be very fast.	Seconds to hours depending on type
Quality assurance	Nondestructive testing (NDT) methods well established	NDT for brazed joints established. Solder inspection can be difficult.	Reasonable confidence in torque control tightening	NDT methods limited

Abbreviations: CTE, coefficient of thermal expansion; NDT, nondestructive testing. Source: Ref 1.5

Table 1.2 Recommended joining processes for various metal groups

Material	Thickness(a)	Shielded metal arc welding	Submerged arc welding	Gas metal arc welding	Flux-cored arc welding	Gas tungsten arc welding	Plasma arc welding	Electroslag welding	Electrogas welding	Resistance welding	Flash welding	Oxyfuel welding	Diffusion welding	Friction welding	Electron beam welding	Laser beam welding	Torch brazing	Furnace brazing	Induction brazing	Resistance brazing	Dip brazing	Infrared brazing	Diffusion brazing	Soldering
Carbon steel	S	X	X	X		X				X	X	X			X	X	X	X	X	X	X	X	X	X
	I	X	X	X	X	X				X	X	X		X	X	X	X	X	X	X	X		X	X
	M	X	X	X	X					X	X	X		X	X	X	X	X	X				X	
	T	X	X	X	X			X	X		X	X		X	X			X					X	
Low-alloy steel	S	X	X	X		X				X	X	X	X		X	X	X	X	X	X	X	X	X	X
	I	X	X	X	X	X				X	X		X	X	X	X	X	X	X				X	X
	M	X	X	X	X						X		X	X	X	X	X	X	X				X	
	T	X	X	X	X			X		X	X		X	X	X		X							
Stainless steel	S	X	X	X		X	X			X	X	X	X		X	X	X	X	X	X	X	X	X	X
	I	X	X	X	X	X	X			X	X		X	X	X	X	X	X	X				X	X
	M	X	X	X	X		X				X		X	X	X	X	X	X	X				X	
	T	X	X	X	X			X			X		X	X	X			X					X	

(continued)

(a) S, sheet, up to 3 mm (⅛ in.); I, intermediate, 3 to 6 mm (⅛ to ¼ in.); M, medium, 6 to 19 mm (¼ to ¾ in.); T, thick, 19 mm (¾ in.) and up. Source: Ref 1.4

Table 1.2 (continued)

Material	Thickness(a)	Shielded metal arc welding	Submerged arc welding	Gas metal arc welding	Flux-cored arc welding	Gas tungsten arc welding	Plasma arc welding	Electroslag welding	Electrogas welding	Resistance welding	Flash welding	Oxyfuel welding	Diffusion welding	Friction welding	Electron beam welding	Laser beam welding	Torch brazing	Furnace brazing	Induction brazing	Resistance brazing	Dip brazing	Infrared brazing	Diffusion brazing	Soldering
Cast iron	I	X										X					X	X	X				X	X
	M	X	X	X	X							X					X	X	X				X	X
	T	X	X	X	X							X						X					X	
Nickel and alloys	S	X		X		X	X			X	X	X			X	X	X	X	X	X	X	X	X	X
	I	X	X	X		X	X			X	X			X	X	X	X	X	X				X	X
	M	X	X	X			X				X			X	X	X	X	X					X	
	T	X		X				X			X			X	X			X					X	
Aluminum and alloys	S	X		X		X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	I	X		X		X				X	X		X	X	X	X	X	X			X		X	X
	M	X		X		X					X			X	X		X	X			X		X	
	T	X		X				X	X		X				X			X					X	
Titanium and alloys	S			X		X	X			X	X		X		X	X		X	X			X	X	
	I			X		X	X				X		X	X	X	X		X					X	
	M			X		X	X				X		X	X	X	X		X					X	
	T			X							X		X		X		X	X					X	
Copper and alloys	S			X		X	X				X				X		X	X	X	X			X	X
	I			X			X				X			X	X		X	X		X			X	X
	M			X							X			X	X		X	X					X	
	T			X							X				X			X					X	
Magnesium and alloys	S			X		X				X					X	X	X	X			X		X	
	I			X		X				X	X			X	X	X	X	X			X		X	
	M			X							X			X	X	X		X					X	
	T			X							X				X									
Refractory alloys	S			X		X	X			X	X				X		X	X	X	X		X	X	
	I			X			X				X				X		X	X					X	
	M									X	X													
	T																							

(a) S, sheet, up to 3 mm (⅛ in.); I, intermediate, 3 to 6 mm (⅛ to ¼ in.); M, medium, 6 to 19 mm (¼ to ¾ in.); T, thick, 19 mm (¾ in.) and up. Source: Ref 1.4

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Chapter 1: Introduction to Joining

References

1.1 K. Sampath, Design for Joining, *Materials Selection and Design*, Vol 20, *ASM Handbook*, ASM International, 1997 doi: 10.31399/asm.hb.v20.a0002488

1.2 F.C. Campbell, Structural Joints—Bolted and Bonded, *Structural Composite Materials*, ASM International, 2010, p 449

1.3 Metallography and Microstructures of Weldments, *Metallography and Microstructures*, Vol 9, *ASM Handbook*, ASM International, 2004 doi: 10.31399/asm.hb.v09.a0003785

1.4 Joining, *Metals Handbook Desk Edition*, 2nd ed., ASM International, 1998, p 1052 doi: 10.31399/asm.hb.mhde2.a0003205

1.5 E.M. Petrie, An Introduction to Adhesives and Sealants, *Handbook of Adhesive and Sealants*, McGraw Hill, 2000, p 20

Selected References

- *Adhesives and Sealants*, Vol 3, *Engineered Materials Handbook*, ASM International, 1990
- *Brazing Handbook*, American Welding Society, 1991
- G. Humpston and D.M. Jacobson, *Principles of Soldering and Brazing*, ASM International, 1993
- R.W. Messler, An Overview of Joining Processes, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005551
- W.C. Mohr and O.W. Blodgett, General Design Considerations for Arc Welding Processes, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005558
- *Welding Technology*, Vol 1, *Welding Handbook*, 8th ed., American Welding Society, 1987

Chapter 2: Arc Welding of Metals

References

2.1 Introduction and Overview of Joining, *Metals Handbook Desk Edition*, 2nd ed., ASM International, 1998 doi: 10.31399/asm.hb.mhde2.a0003205

2.2 K.A. Lyttle, Shielding Gases for Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001340

2.3 Arc Welding, *Metals Handbook Desk Edition*, 2nd ed., ASM International, 1998 doi: 10.31399/asm.hb.mhde2.a0003206

2.4 R.W. Messler, Overview of Welding Processes, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005552

2.5 L.E. Allgood, Submerged Arc Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005566

2.6 C. Conrardy, Gas Metal Arc Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005572

2.7 L.E. Allgood, Gas-Tungsten Arc Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005590

2.8 G. Ken-Hicken, Gas-Tungsten Arc Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001356

2.9 “Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting,” AWS A5.12/A5.12M, American Welding Society, 2009

2.10 I.D. Harries, Plasma Arc Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005582

2.11 “Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding,” AWS A5.25/A5.25M, American Welding Society, 2009

2.12 “Specification for Carbon and Low-Alloy Steel Electrodes for Electrogas Welding,” AWS A5.26/A5.26M, American Welding Society, 2009

Selected References

- L. Algood, Introduction to Arc Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005580

- R. Blondeau, *Metallurgy and Mechanics of Welding*, John Wiley & Sons, 2008 doi: 10.1002/9780470611272

- S.D. Brandi, S. Liu, and R.D. Thomas, Electroslag and Electrogas Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005591

- I.D. Harris, Plasma Gas Metal Arc Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005598

- D.B. Holliday, Gas-Metal Arc Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001354

- Introduction and Overview of Joining, *Metals Handbook Desk Edition*, 2nd ed., ASM International, 1998 doi: 10.31399/asm.hb.mhde2.a0003205

- R.H. Juers, Shielded Metal Arc Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001353

- S. Knostman, Shielded Metal Arc Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005570

- G. Mathers, *The Welding of Aluminum and Its Alloys*, CRC Press, 2002 doi: 10.1533/9781855737631

- M.T. Merlo, Flux-Cored Arc Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005601

- R.W. Messler, *Principles of Welding Processes*, Wiley-VCH, 2005

- D.W. Meyer, Flux-Cored Arc Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001355

- D.L. Olson, S. Liu, R.H. Frost, G.R. Edwards, and D.A. Fleming, Nature and Behavior of Fluxes Used for Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001339

- *Welding Processes*, Vol 2, *Welding Handbook*, 8th ed., American Welding Society, 1997

- K. Weman, *Welding Process Handbook*, CRC Press, 2003 doi: 10.1533/9781855738539

Chapter 3: Resistance Welding

References

3.1 R.W. Messler, *Joining of Materials and Structures*, Elsevier, 2004 doi: 10.1016/B978-075067757-8/50014-2

3.2 R.W. Messler, Overview of Welding Processes, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005552

3.3 Metallography and Microstructures of Weldments, *Metallography and Microstructures*, Vol 9, *ASM Handbook*, ASM International, 2004 doi: 10.31399/asm.hb.v09.a0003785

3.4 Resistance Welding, *Metals Handbook Desk Edition*, 2nd ed., ASM International, 1998 doi: 10.31399/asm.hb.mhde2.a0003207

3.5 *Welding Processes*, Vol 2, *Welding Handbook*, 8th ed., American Welding Society, 1997

Selected References

- J.E. Gould, Projection Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001364

- J.E. Gould and K. Short, Fundamentals of Solid-State Resistance Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005593

- W.R. Kanne, Upset Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001367

- M.J. Karagoulis, Resistance Seam Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001365

- H.J. Latimer and R.B. Matteson, Flash Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001366

- R. Matteson and T. Winfield, Resistance Seam Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005608

- R.W. Messler, *Principles of Welding Processes*, Wiley-VCH, 2005

- M.D. Tumuluru, Resistance Spot Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005594

- N.T. Williams, Resistance Spot Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001363

- H. Zhang and J. Senkara, *Resistance Welding Fundamentals and Applications*, CRC Press, 2006

Chapter 4: Other Fusion Welding Processes

References

4.1 Other Fusion Welding Processes, *Metals Handbook Desk Edition*, 2nd ed., ASM International, 1998 doi: 10.31399/asm.hb.mhde2.a0003208

4.2 “Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding,” AWS A5.2/A5.2M, American Welding Society, 2007

4.3 H.A. Chambers, Stud Arc Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001360

4.4 R.L. Alley, Capacitor Discharge Stud Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001361

4.5 M. Kimchi, High-Frequency Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005583

4.6 Electron-Beam Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001369

4.7 R.W. Messler, Overview of *Welding Processes*, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005552

4.8 Metallography and Microstructures of Weldments, *Metallography and Microstructures*, Vol 9, *ASM Handbook*, ASM International, 2004 doi: 10.31399/asm.hb.v09.a0003785

4.9 B.M. Victor, Hybrid Laser-Arc Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005600

4.10 B. Schwartz, Thermit Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001373

Selected References

- W. Ballis, Oxyfuel Gas Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001372

- P.W. Hochanadel, J.W. Elmer, K. Lachenberg, P. Burgardt, and D.D. Kautz, Electron-Beam Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005615

- J. Mazumder, Laser-Beam Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001370

Chapter 5: Metallurgy Variables in Fusion Welding

References

5.1 T.W. Eager, Energy Sources Used for Fusion Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001332

5.2 C.L. Tsai and C.M. Tso, Heat Flow in Fusion Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001333

5.3 H.D. Solomon, Fundamentals of Weld Solidification, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001338

5.4 Metallography and Microstructures of Weldments, *Metallography and Microstructures*, Vol 9, *ASM Handbook*, ASM International, 2004 doi: 10.31399/asm.hb.v09.a0003785

5.5 P.R. Vishnu, Solid-State Transformations in Weldments, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001341

5.6 R.M. Messler, *Joining of Materials and Structures*, Elsevier, 2004 doi: 10.1016/B978-075067757-8/50014-2

5.7 K. Mascubuchi, Residual Stresses and Distortion, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001475

5.8 S. Kou, *Welding Metallurgy*, 2nd ed., John Wiley & Sons, 2003 doi: 10.1002/0471434027

5.9 Classification of Weld Discontinuities, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001472

5.10 M.J. Cieslak, Cracking Phenomena Associated with Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001342

5.11 T. Jutla, Fatigue and Fracture Control of Weldments, *Fatigue and Fracture*, Vol 19, *ASM Handbook*, 1996 doi: 10.31399/asm.hb.v19.a0002384

5.12 C.B. Dallam and B.K. Damkroger, Characterization of Welds, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001343

Selected References

- R. Blondeau, *Metallurgy and Mechanics of Welding*, John Wiley & Sons, 2008 doi: 10.1002/9780470611272

- J.N. DuPont, Fundamentals of Weld Solidification, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005609

- T.W. Eagar and A.D. Mazzeo, Welding Process Fundamentals, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005577

- Z. Feng, *Processes and Mechanisms of Welding Residual Stress and Distortion*, CRC Press, 2005 doi: 10.1533/9781845690939

- J.F. Lancaster, *Metallurgy of Welding*, 6th ed., Woodhead Publishing, 1999 doi: 10.1533/9781845694869

- M. Maalekian, Solid-State Transformations in Weldments, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005613

- R.W. Messler, *Principles of Welding Processes*, Wiley-VCH, 2005

- O.R. Myhr and Ø. Grong, Factors Influencing Heat Flow in Fusion Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005573

- C.L. Tsai, Heat Flow in Fusion Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005588

- W. Zhang, Fluid Flow Phenomena During Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005579

Preview for: *Joining: Understanding the Basics*, edited by F.C. Campbell, ASM International, 2011
Full digital book available at https://doi.org/10.31399/asm.tb.jub.9781627083065

Chapter 6: Solid-State Welding and Bonding

References

6.1 Solid-State Welding Processes, *Metals Handbook Desk Edition*, 2nd ed., ASM International, 1998 doi: 10.31399/asm.hb.mhde2.a0003209

6.2 M.W. Mahoney, Fundamentals of Diffusion Bonding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001350

6.3 T.B. Jefferson and G. Woods, *Metals and How to Weld Them*, James F. Lincoln Arc Welding Foundation, 1954

6.4 Forge Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001377

6.5 Roll Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001380

6.6 Coextrusion Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001379

6.7 K. Thomas, Cold Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001378

6.8 N. Bay, Cold Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005581

6.9 J.W. Elmer and D.D. Kautz, Fundamentals of Friction Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001349

6.10 R.S. Mishra and M.W. Mahoney, *Friction Stir Welding and Processing*, ASM International, 2007

6.11 R.A. Patterson, Fundamentals of Explosion Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001351

6.12 J. Devine, Ultrasonic Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001384

Preview for: *Joining: Understanding the Basics*, edited by F.C. Campbell, ASM International, 2011
Full digital book available at https://doi.org/10.31399/asm.tb.jub.9781627083065

Selected References

- J.G. Banker and E.G. Reineke, Explosion Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001376

- J.E. Gould, Mechanisms of Bonding for Solid-State Welding Processes, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005574

- D.D. Kautz, Fundamentals of Friction Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005575

- P.S. Korinko, Forge and Coextrusion Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005567

- W. W. Lehrheuer, High-Temperature Solid-State Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001374

- L. Li and C. Zhang, Fundamentals of Ultrasonic Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005619

- S. Liu, J. Banker, and C. Prothe, Explosion Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005602

- R.S. Rosen, Low-Temperature Solid-State Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001375

- T. Stotler, Procedure Development and Practice Considerations for Inertia and Direct-Drive Rotary Friction Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005596

- S. Tsang, Friction Welding, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001381

Chapter 7: Brazing and Soldering

References

7.1 T. Oyama and H. Mizuhara, Furnace Brazing, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001386

7.2 M.M. Schwartz, Fundamentals of Brazing, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001345

7.3 *Brazing Handbook*, 4th ed., American Welding Society, 1991, p 4

7.4 M.M. Schwartz, *Principles of Soldering*, ASM International, 2004

7.5 Brazing, *Metals Handbook Desk Edition*, 2nd ed., ASM International, 1998 doi: 10.31399/asm.hb.mhde2.a0003210

7.6 C.E. Fuerstenau, Torch Brazing, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001385

7.7 J.F. Libsch, Induction Brazing, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001387

7.8 D.D. Peter, Dip Brazing, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001388

7.9 W.D. Kay, Diffusion Brazing, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001390

7.10 Soldering, *Metals Handbook Desk Edition*, 2nd ed., ASM International, 1998 doi: 10.31399/asm.hb.mhde2.a0003211

7.11 K.N. Tu, J.O. Suh, and A.T. Wu, Tin Whisker Growth on Lead-Free Solder Finishes, *Lead-Free Solder Interconnect Reliability*, ASM International, 2005

7.12 P.T. Vianco, Wave Soldering, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001401

Selected References

- J. Bath, *Lead-Free Soldering*, Springer, 2007 doi: 10.1007/978-0-387-68422-2

- Brazing, *Welding Processes*, Vol 2, *Welding Handbook*, 8th ed., American Welding Society, 1997

- P. Roberts, *Industrial Brazing Practice*, CRC Press, 2004 doi: 10.1201/9780203488577

- M.M. Schwartz, Introduction to Brazing and Soldering, *Welding, Brazing, and Soldering*, Vol 6, *ASM Handbook*, ASM International, 1993 doi: 10.31399/asm.hb.v06.a0001344

- D. Shangguan, Lead-Free Soldering and Environmental Compliance: An Overview, *Lead-Free Solder Interconnect Reliability*, ASM International, 2005

- Soldering, *Welding Processes*, Vol 2, *Welding Handbook*, 8th ed., American Welding Society, 1997

Chapter 8: Mechanical Fastening

References

8.1 F.C. Campbell, Chapter 11, Machining and Assembly, *Structural Composite Materials*, ASM International, 2010

8.2 F.C. Campbell, Chapter 17, Structural Joints—Bolted and Bonded, *Structural Composite Materials*, ASM International, 2010

8.3 W.J. Jensen, Failures in Mechanical Fasteners, *Failure Analysis and Prevention*, Vol 11, *ASM Handbook*, ASM International, 1986 doi: 10.31399/asm.hb.v11.a0001812

8.4 R.S. Shoberg, Mechanical Testing of Threaded Fasteners and Bolted Joints, *Mechanical Testing and Evaluation*, Vol 8, *ASM Handbook*, ASM International, 2000 doi: 10.31399/asm.hb.v08.a0003323

8.5 M.P. Groover, *Fundamentals of Modern Manufacturing—Materials, Processes, and Systems*, Prentice Hall, 1996.

8.6 R.D. Cullum, E.N. Gregory, and R. Goss, Fabrication, *Manufacturing Engineer's Reference Book*, Butterworth-Heinemann, 1993 doi: 10.1016/B978-0-08-052395-8.50013-8

8.7 F.C. Campbell, Chapter 14, Fatigue, *Elements of Metallurgy and Engineering Alloys*, ASM International, 2008 doi: 10.31399/asm.tb.emea.9781627082518

Selected References

- R.T. Barrett, "Fastener Design Manual," NASA Reference Publication 1228, National Aeronautics and Space Administration, 1990

- G.G. Born, "Single-Pass Drilling of Composite/Metallic Stacks," Paper 2001-01-2573, SAE International, 2001 doi: 10.4271/2001-01-2573

- "Fastenal Technical Reference Guide," Fastenal Industrial and Construction Supplies, 2005

- A. Leon, "Developments in Advanced Coldworking," SAE 982145, SAE International, 1998 doi: 10.4271/982145

- D.W. Oplinger, Mechanical Fastening and Adhesive Bonding, *Handbook of Composites*, Chapman Hall, 1982

- R.T. Parker, Mechanical Fastener Selection, *Composites*, Vol 21, *ASM Handbook*, ASM International, 2001, p 651–658 doi: 10.31399/asm.hb.v21.a0003427

- R.O. Parmley, *Standard Handbook of Fastening and Joining*, 3rd ed., McGraw-Hill, 1996

- M.J. Robin, Mechanical Fasteners, *Mechanical Engineers' Handbook*, 2nd ed., John Wiley & Sons, 1998

Chapter 9: Adhesive Bonding

References

9.1 F.C. Campbell, Structural Joints—Bolted and Bonded, *Structural Composite Materials*, ASM International, 2010

9.2 F.C. Campbell, Adhesive Bonding, *Structural Composite Materials*, ASM International, 2010

9.3 E.M. Petrie, Surfaces and Surface Preparation, *Handbook of Adhesives and Sealants*, McGraw-Hill, 2000

9.4 F.C. Campbell, Secondary Adhesive Bonding of Polymer-Matrix Composites, *Composites*, Vol 21, *ASM Handbook*, ASM International, 2001 doi: 10.31399/asm.hb.v21.a0003489

9.5 M.P. Groover, *Fundamentals of Modern Manufacturing—Materials, Processes, and Systems*, Prentice Hall, 1996

9.6 Adhesives, *Engineered Materials Handbook Desk Edition*, ASM International, 1995 doi: 10.31399/asm.hb.emde.a0003047

9.7 R.F. Wegman, *Surface Preparation Techniques for Adhesive Bonding*, Noyes Publications, 1989

9.8 H.M. Clearfield, D.K. McNamara, and G.D. Davis, Surface Preparation of Metals, *Engineered Materials Handbook*, Vol 3, *Adhesives and Sealants*, ASM International, 1990

Selected References

- R.B. Heslehurst and L.J. Hart-Smith, The Science and Art of Structural Adhesive Bonding, *SAMPE Journal*, Vol 38 (No. 2), March/April 2002, p 60–71

- B.M. Parker, The Effect of Composite Prebond Moisture on Adhesive-Bonded CFRP-CFRP Joints, *Composites*, Vol 14, July 1983, p 226–232 doi: 10.1016/0010-4361(83)90008-3

- E.M. Petrie, Primers and Adhesion Promoters, *Handbook of Adhesives and Sealants*, McGraw-Hill, 2000

- “Redux Bonding Technology,” Hexcel Composites, December 2001

- J.D. Venables, D.K. McNamara, J.M. Chen, T.S. Sun, and J.L. Hopping, Oxide Morphologies on Aluminum Prepared for Adhesive Bonding, *Applications of Surface Science*, Vol 3, 1979, p 88–98 doi: 10.1016/0378-5963(79)90063-1

Chapter 10: Materials Issues in Joining

References

10.1 J. R. Davis, Hardfacing, Weld Cladding, and Dissimilar Metal Joining, *Welding, Brazing, and Soldering*, Vol 20, *ASM Handbook*, ASM International, 1993

10.2 Joining and Assembly of Plastics, *Engineered Materials Handbook Desk Edition*, ASM International, 1995 doi: 10.31399/asm.hb.emde.a0003021

10.3 F.C. Campbell, Chapter 17, Structural Joints—Bolted and Bonded, *Structural Composite Materials*, ASM International, 2010

10.4 F.C. Campbell, Chapter 11, Machining and Assembly, *Structural Composite Materials*, ASM International, 2010

10.5 F.C. Campbell, Chapter 6, Thermoplastic Composite Fabrication Processes, *Structural Composite Materials*, ASM International, 2010

10.6 Glass Processing, *Engineered Materials Handbook Desk Edition*, ASM International, 1995 doi: 10.31399/asm.hb.emde.a0003065

10.7 Joining Ceramics, *Engineered Materials Handbook Desk Edition*, ASM International, 1995 doi: 10.31399/asm.hb.emde.a0003056

Selected References

- J.N. DuPont, Dilution in Fusion Welding, *Welding Fundamentals and Processes*, Vol 6A, ASM International, 2011 doi: 10.31399/asm.hb.v06a.a0005589
- D.A. McCarville and H.A. Schaefer, Processing and Joining of Thermoplastic Composites, *Composites*, Vol 21, *ASM Handbook*, ASM International, 2001, p 633–645 doi: 10.31399/asm.hb.v21.a0003425
- C.A. Harper, *Handbook of Plastics, Elastomers, and Composites*, 4th ed., McGraw-Hill, 2004
- E.M. Petrie, *Handbook of Adhesives and Sealants*, McGraw-Hill, 2000
- M.M. Schwartz, *Ceramic Joining*, ASM International, 1990
- M.J. Troughton, *Handbook of Plastic Joining*, 2nd ed., William Andrew Inc., 2008