Chapter 10: Joining Processes

Introduction. Joining is an all-inclusive term covering processes such as **welding**, **brazing**, **soldering**, **adhesive bonding**, and **mechanical fastening**. These processes are an essential and important aspect of manufacturing and assembly operations. American Welding Society (AWS) categorize joining processes into the following three major categories: 1- Welding, 2- Adhesive bonding and 3- Mechanical fastening. Welding processes, in turn, are generally classified into three basic categories: **Fusion Welding**, **Solid-state Welding**, Brazing and Soldering. Fusion welding is defined as the melting together and **coalescing** of materials by means of heat, usually supplied by chemical or electrical means. **Filler** metals may or may not be used in fusion welding.

In solid-state welding, joining takes place without fusion; consequently, there is no liquid (molten) phase in the joint. The basic processes in this category are **diffusion bonding** and cold, ultrasonic, friction, **resistance**, and **explosion** welding. Brazing uses filler metals and involves lower temperatures than in welding. Soldering uses similar filler metals (**solders**) and involves even lower temperatures. Adhesive bonding has unique applications requiring strength, **sealing**, thermal and electrical **insulating**, **vibration damping**, and resistance to corrosion between dissimilar metals. Mechanical fastening involves traditional methods of using various **fasteners**, such as bolts, nuts, and rivets. The joining of plastics can be accomplished by adhesive bonding, fusion by various external or internal heat sources, and mechanical fastening.

Fusion Welding. Fusion welding processes involve partial melting and fusion between two members to be joined. Here, fusion welding is defined as melting together and coalescing materials by means of heat. Filler metals, which are metals added to the weld area during welding, also may be used. Welds made without the use of filler metals are known as **autogenous welds**.

Oxyfuel-gas Welding. Oxyfuel-gas welding (OFW) is a general term to describe any welding process that uses a fuel gas combined with oxygen to produce a **flame**, which is the source of the heat required to melt the metals at the joint. The most common gas-welding process uses acetylene; the process is known as oxyacetylene-gas welding (OAW) and is typically used for structural metal fabrication and repair work (see Fig. 1).

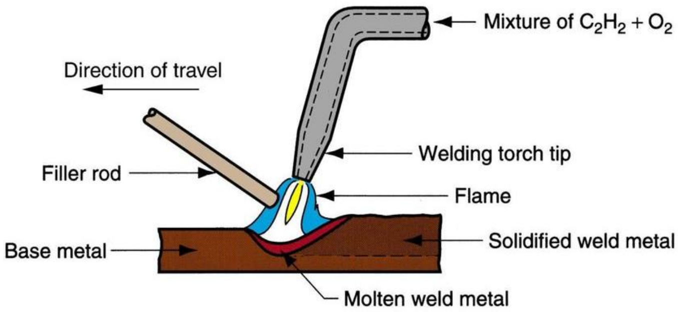

Fig. 1 A typical oxyacetylene-gas welding process.

A. Fill in the blanks with the following words.

nonconsumable, polarity, electrical, arc, oxidation

Arc-welding Processes. In arc welding, developed in the mid-1800s, the heat required is obtained from ……………… energy. The process involves either a **nonconsumable** or a **consumable** electrode. An AC or a DC power supply produces an ……………… between the tip of the electrode and the workpiece to be welded. The arc generates temperatures of about 30,000°C, much higher than those developed in oxyfuel–gas welding. In ………………-electrode welding processes, the electrode is typically a tungsten electrode. Because of the high temperatures involved, an externally supplied **shielding gas** is necessary in order to prevent ……………… of the **weld zone**. Typically, **direct current** is used and its ……………… (the direction of current flow) is important. The selection of current levels depends on such factors as the type of electrode, the metals to be welded, and the depth and width of the weld zone.

Shielded Metal-arc Welding. Shielded metal-arc welding (SMAW) is one of the oldest, simplest, and most versatile joining processes; consequently, about 50% of all industrial and maintenance welding is performed by this process. The electric arc is generated by touching the tip of a **coated electrode** against the workpiece, and withdrawing it quickly to a distance sufficient to maintain the arc (Fig. 2). The electrodes are in the shapes of thin, long round rods (hence the process also is referred to as **stick welding**) that are held manually. The heat generated melts a portion of the electrode tip, its coating, and the base metal in the immediate arc area. The molten metal consists of a mixture of the base metal (the workpiece), the electrode metal, and substances from the coating on the electrode; this mixture forms the weld when it solidifies. The electrode coating deoxidizes the weld area and provides a shielding gas, to protect it from oxygen in the environment.

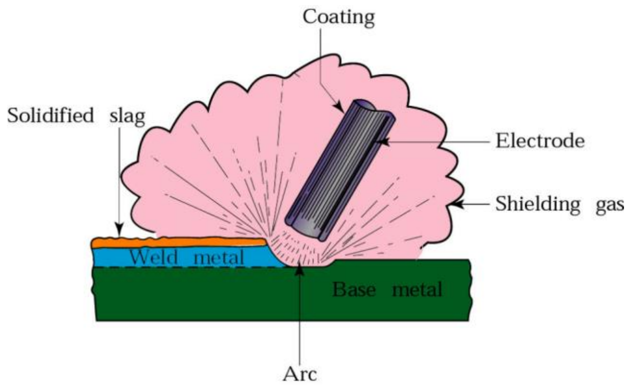

Fig. 2 Schematic illustration of the shielded metal-arc welding process.

<u>Laser-beam Welding.</u> Laser-beam welding (LBW) utilizes a high-power laser beam as the source of heat to produce a fusion weld. Because it can be focused onto a very small area, the beam has high energy density and deep-penetrating capability. The laser beam can be directed, shaped, and focused precisely on the workpiece; laser spot diameters can be as small as 0.2 mm. Consequently, this process is particularly suitable for welding deep and narrow joints, with depth-to-width ratios typically ranging from 4 to 10. Laser-beam welding has become extremely widespread and is now used in most industries. The laser beam may be pulsed (in milliseconds), with power levels up to 100 kW for such applications as the spot welding of thin materials. Continuous multi-kW laser systems are used for deep welds on thick sections. Laser-beam welding produces welds of good quality with minimum shrinkage or distortion. Laser welds have good strength and are generally ductile and free of porosity.

B. Fill in the blanks with the following words.

microstructure, physical, cold work, base, cooling

<u>Heat-affected Zone.</u> The heat-affected zone (HAZ) is within the ……………… metal itself (Fig. 3). It has a ……………… different from that of the base metal prior to its welding, because it has been temporarily subjected to elevated temperatures during welding. The portions of the base metal that are far away from the heat source do not undergo microstructural changes during welding, because of the far lower temperature to which they are subjected. The properties and microstructure of the HAZ depend on (a) the rate of heat input and ……………… and (b) the temperature to which this zone was raised. In addition to metallurgical factors (such as the original grain size, grain orientation, and degree of prior ………………), ……………… properties (such as the specific heat and thermal conductivity of the metals) also influence the size and characteristics of the HAZ.

Weldability. The weldability of a metal is generally defined as its capability to be welded into a specific structure that has certain properties and characteristics, and will satisfactorily meet service requirements. Weldability involves a large number of variables, thus generalizations are difficult. Material characteristics, such as alloying elements, impurities, inclusions, grain structure, and processing history, of both the base metal and the filler metal, are all important. For example, the weldability of steels decreases with increasing carbon content, because of martensite formation (which is hard and brittle), and thus reduces the strength of the weld. Coated steel sheets also can present various challenges in welding, depending on the type and thickness of the coating.

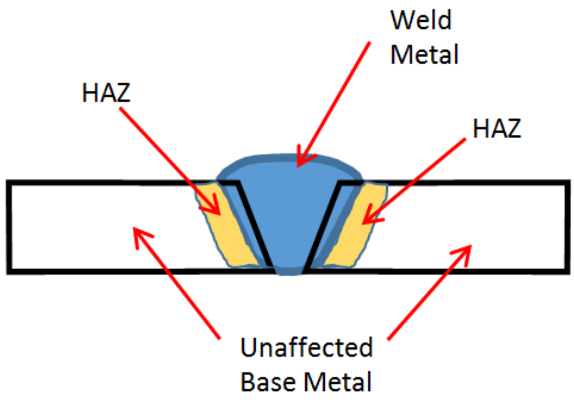

Fig. 3 Schematic illustration of the heat affected zone (HAZ).

Brazing. Brazing is a joining process in which a filler metal is placed at the periphery or between the **interfaces** of the faying surfaces to be joined. The temperature is then raised sufficiently to melt the filler metal, but not the components (the base metal), as would be the case in fusion welding. Brazing is derived from the word brass meaning "to harden;" the process was first used as far back as 3000 to 2000 B.C. It will be noted that brazing is a liquid-solid-state bonding process. Upon cooling and solidification of the filler metal, a strong joint is obtained. Filler metals for brazing typically melt above 450°C, which is below the melting point (solidus temperature) of the metals to be joined. Figure 4 shows a typical brazing operation, where a filler (braze metal) in the shape of wire is placed along the periphery of the components to be joined. Heat is then applied, by various external means, melting the braze metal and, by **capillary** action, filling the closely fitting space (called joint **clearance**) at the interfaces (Fig. 4b). In braze welding, filler metal (typically brass) is deposited at the joint by a technique similar to oxyfuel–gas welding. Intricate, lightweight shapes can be joined rapidly and with little distortion, good joint strength, and with dissimilar metals.

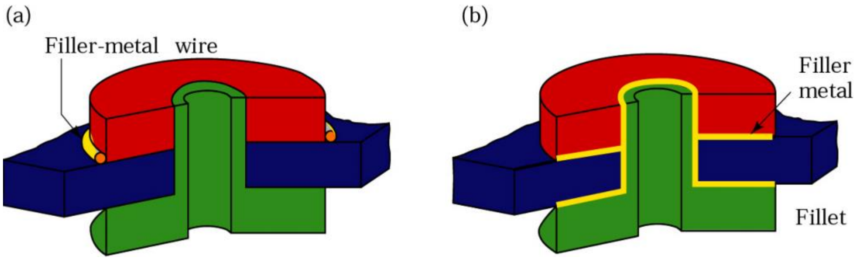

Fig. 4 An example of furnace brazing: (a) before, (b) after. Note that the filler metal is a shaped wire.

C. Fill in the blanks with the following words.

compositions, characteristics, torches, toxicity, tension, capillary

Soldering. In soldering, the filler metal (**<u>solder</u>**) melts at a relatively low temperature. As in brazing, the solder fills the joint, by ……………… action, between closely fitting or closely placed components. Heat sources for soldering are typically **<u>soldering irons</u>**, ……………… or ovens. The word "solder" is derived from the Latin solidare, meaning "to make solid." Soldering with copper–gold and tin–lead alloys was first practiced as far back as 4000 to 3000 B.C. Two important characteristics of solders are low surface ……………… and high **<u>wetting</u>** capability. Solders melt at the eutectic point of the solder alloy. Solders traditionally have been tin–lead alloys in various proportions. A solder of 61.9% Sn– 8.1% Pb composition, for example, melts at 188°C, whereas tin melts at 232°C and lead at 327°C. For special applications and higher joint strength, especially at elevated temperatures, other solder ……………… are tin–zinc, lead–silver, cadmium–silver, and zinc–aluminum alloys. Because of the ……………… of lead and its adverse effects on the environment, lead-free solders are available. Since the European union prohibited the intentional addition of lead to consumer electronics in 2006, tin–silver–copper solders have come into wide use, with a typical composition of 96.5% tin, 3.0% silver, and 0.5% copper. A fourth element, such as zinc or manganese, is often added to provide desired mechanical or thermal ……………… . For nonelectrical applications, a large number of solders are available, and can also incorporate cadmium, gold, bismuth, and indium.

Adhesive-bonding. One of the most versatile joining process is the use of adhesives between two surfaces, generally using a rubber or polymer as the filler material. A common example of adhesive-bonding is plywood, where several layers of wood are bonded with wood glue. Modern plywood was developed in 1905, but the practice of adhesive-bonding of wood layers, using animal glue, dates back to 3500 B.C. Adhesive-bonding has gained increased acceptance in manufacturing ever since its first use on a large scale: the assembly of load-bearing components in aircraft during World War II (1939– 1945). Adhesives are available in various forms: liquid, **paste**, solution, **emulsion**, powder, tape, and film. When applied, adhesives typically are about 0.1 mm thick. To meet the requirements of a particular application, an adhesive may require one or more of the following properties: strength- shear and **peel**, toughness, resistance to various fluids and chemicals, resistance to environmental **degradation**, including heat and **moisture** and capability to wet the surfaces to be bonded.

Mechanical Fastening. Two or more components may have to be joined or fastened in such a way that they can be taken apart during the product's service life or life cycle. Numerous products, such as pens, shaft couplings, car wheels, appliances, engines, and bicycles, have components that are fastened mechanically. Mechanical fastening may be preferred over other methods for the following reasons:

- Ease of manufacturing
- Ease of assembly and transportation
- Ease of disassembly, maintenance, parts replacement, or repair
- Ease in creating designs that require movable joints such as hinges, sliding mechanisms, and adjustable components and fixtures
- Lower overall cost of manufacturing the product

The most common method of mechanical fastening is by the use of **fasteners**; these may be pins, rivets, or **keys**; threaded fasteners, such as bolts, nuts, **screws**, and **studs**; or other types, such as various integrated fasteners. Also known as mechanical assembly, mechanical fastening generally requires that the components have holes through which the fasteners are inserted. These joints may be subjected to both shear and tensile stresses, and thus should be designed to resist such forces.

CASE STUDY. Friction Welding of Pistons

There has been a sustained effort among heavytruck manufacturers to design and manufacture diesel engines with reduced **emissions**. **Exhaust-gas** **recirculation** (reintroduction of a portion of the spent exhaust gases into the intake stream of the engine) has become standard, and is known to reduce nitrousoxide emissions. However, this strategy leads to less efficient combustion and lower component **durability**, because of the presence of abrasive-wear particles and acids that are recirculated into the engine. To maintain and even improve efficiency, engine manufacturers have increased cylinder pressures and operating temperatures, which together lead to an even more demanding environment for engine components. The traditional aluminum pistons in diesel engines were found not to function reliably in modern engine designs. The problems identified with pistons were (a) a tendency to "mushroom" and fracture under the high firing pressures in the cylinder, (b) inadequate cooling of the piston, and (c) **scuffing** (wear) at the pin that joins the piston to the connecting rod. One solution, shown in Fig. 5, is a **Monosteel** piston.

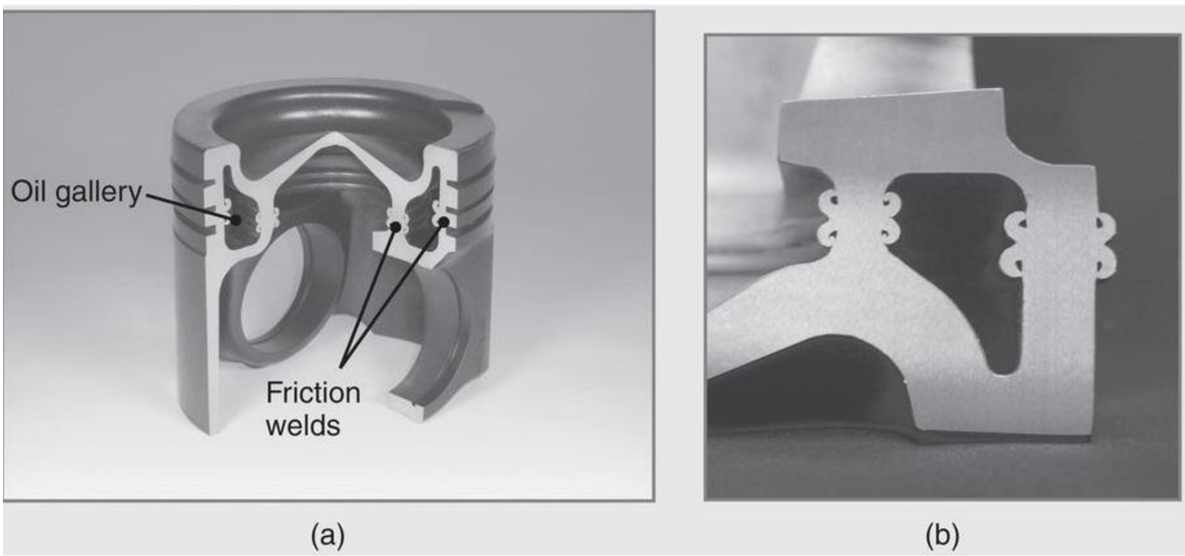

Fig. 5 The Monosteel piston. (a) Cutaway view of the piston, showing the oil gallery and the friction-welded sections; (b) detail of the friction welds before the external flash is removed and cylindrical grooves are machined.

Monosteel pistons are produced from two forged components, which are then machined prior to welding. The process used to join these components is inertia friction welding, which has the following advantages in this particular application: • The welding process leads to well-controlled, reliable, and **repeatable** high-quality welds. • Friction welds are continuous and do not involve porosity, thereby producing a high-strength weld that seals the oil gallery. • The welding process is fairly straightforward to optimize, with the main process variables being energy (or spindle speed for a given flywheel) and contact pressure.

Because it is entirely machine controlled, friction welding does not require operator **intervention** or **expertise**. Although the capital investment is significant, as compared with that of other appropriate welding technologies, weld quality and the ability to weld in this application is significantly more favorable.

Video: What are joining processes (Click this link or scan the QR code).

D. Translate the following sentences into English.

۱. در جوشکاری مقاومتی نقطه ای، نوک های دو الکترود استوانه ای توپر روبروی هم، اتصال لب روی هم دو ورق فلزی را لمس می کند و گرمای مقاومتی سبب ایجاد یک جوش نقطه ای می شود.

۲. در جوشکاری اصطکاکی، گرمای لازم برای جوشکاری از طریق اصطکاک در فصل مشترک دو قطعه ای که به هم متصل می شوند، ایجاد می شود.

۳. لحیم سخت و نرم فرآیندهای اتصالی هستند که متکی به ذوب یا اعمال فشار در فصل مشترک اتصال نیستند. در مقابل، در این فرآیندها از فلز پرکننده استفاده می شود که نیاز به افزایش گرما در ناحیه اتصال دارد. این فرآیندها می‌توانند برای اتصال فلزات غیرمشابه با شکل‌های پیچیده و ضخامت های متفاوت استفاده شوند.

Resistance Spot Welding (RSW)	جوشکاری مقاومتی نقطه ای
Lap joint	اتصال لب روی هم
Friction welding (FRW)	جوشکاری اصطکاکی
Interface	فصل مشترک