

Lecture 8. Joining processes

Almost all products are assemblies of a large number of components. Some of the components or sub-assemblies can move with respect to each other, others are physically fixed together, with no relative motion possible. The first type of connection is called a *kinematic joint*, and the second type is called a *rigid joint* (or a *structure*). Both types of joints are important in manufacturing, and there are many ways of achieving such joints. The process and methods used for joining depend on the type of joint, the required strength, the materials of the components being joint, the geometry of the components, and cost issues. IN this lecture, we study some of the common methods of joining.

Why do we need joining?

- (a) To restrict some degrees of freedom of motion for components (i.e. to make mechanisms).
- (b) A complex shaped component may be impossible/expensive to manufacture, but it may be possible/cheaper to make it in several parts and then join them.
- (c) Some products are better made as assemblies, since they can be disassembled for maintenance.
- (d) Transporting a disassembled product is sometimes easier/feasible compared to transporting the entire product. A good example of this is the beautiful TsingMa bridge of Hong Kong; individual sections were fabricated, raised to the correct position, and then welded/riveted together to construct the structure.



Figure 1. A section of Tsing Ma Bridge being lifted, before joining.

3.1. Fusion Welding

Welding is the most common joining process for metals. In fusion welding, the joint is made by melting the metal at the interface, so that upon solidification, the components are fused, or joined together. In many cases, extra metal is melted along the joint, to completely fill the joint region.

3.1.1. Oxy-Acetylene Welding (in general, **Oxy-Fuel gas-Welding**, OFW). A mixture of acetylene gas (C_2H_2) and oxygen gas are mixed; acetylene is highly flammable, so the mixture can be lighted and burns generates very high temperatures of up to $3000^{\circ}C$. The flame is used to melt the metal at the joint, along with a filler rod to provide some extra material to fill the gap. The filler rod is coated with **flux**. The flux is a chemical with two uses: part of it evaporates, and the vapor surrounds the region around the molten metal, preventing oxidation. Another part of the flux melts, and dissolves impurities and metal oxides; since these are lighter than the molten metal, they float to the surface and can be removed by a finishing process later.

3.1.2. Arc Welding. Here, the metal is heated by maintaining a very high voltage between the electrode and the metal. This results in dielectric breakdown of the air gap, causing a discharging arc. The temperature at the arc can reach up to $30,000^{\circ}C$ (almost ten times oxy-fuel torches). Notice from Figure 2 (b) that the metal is used as one electrode, and the filler rod as the other electrode; either DC or AC can be used, with typical current ranging between 50A ~300A and typical power of 10kW or more. Typically, DC welders are used for sheet metal, while high power requirements of thick members need AC supply.

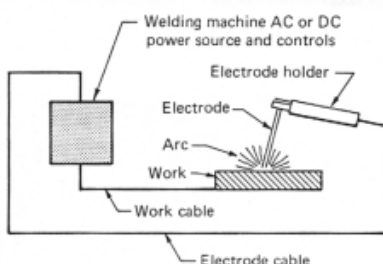


Figure 2 (a) Gas welding (b) Schematic of Arc welding (c) Arc welding is easier to automate using Robots (why?)

3.1.3. Gas Shielded Arc Welding. The most common form is **MIG Welding** (Metal Inert Gas Welding). Here, an inert gas such as Argon or an Argon/Helium mixture is injected to surround the region of the weld. This ensures that the molten metals are shielded from the atmospheric oxygen, and therefore do not oxidize. The electrode may be consumable (i.e. made from the filler material) or non-consumable. Another common form is **Tungsten Inert-Gas Arc welding (TIG Welding)**. Here, the arc is formed between a non-consumable tungsten electrode and the metal being welded. Gas is fed through the torch to shield the electrode and molten weld pool. If filler wire is used, it is added to the weld pool separately. TIG welding can yield better quality and more precise welds. Welding Aluminum almost always requires TIG or MIG welding,

since Al oxidizes easily, and molten Al must not be exposed to oxygen. TIG is also commonly used for welding Titanium, Magnesium, especially thin section welding.

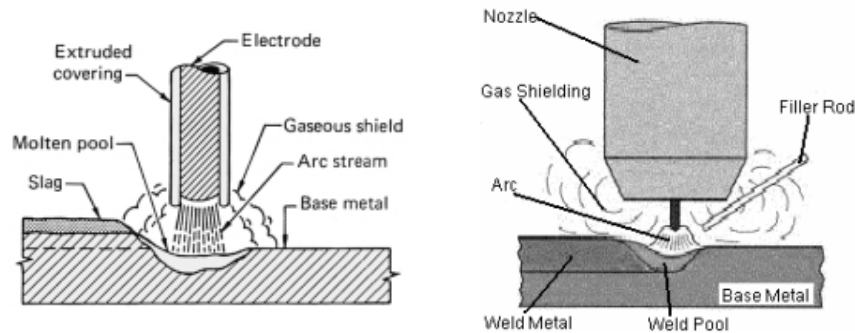


Figure 3 (a) MIG welding (b) TIG welding

3.1.4. Plasma Arc Welding. Plasma is high temperature ionized gas composed of electrons and ions. Plasma arcs are formed by creating the plasma gas by using an arc, and forcing it out as a focused beam through a tiny nozzle. It is useful for deep, narrow welds.

3.1.5. Electron Beam Welding. An electron beam gun creates a stream of electrons (by causing a heated cathode to discharge in a near-vacuum tube.) The beam is focused electro-magnetically, and hits upon the metal, where the kinetic energy of the electrons is converted to heat, causing melting. The process is useful for narrow, deep welds, but is expensive.

3.1.6. Laser-beam Welding. A high power laser can be used to melt metal, and therefore can be used to cut, weld, etc. Typical high power lasers include Nd:Nag and CO₂ lasers, with power levels up to 100kW. This is a very versatile welding process, and can be used for high speed, narrow, deep, welds; it is also useful for high precision, low distortion welds.

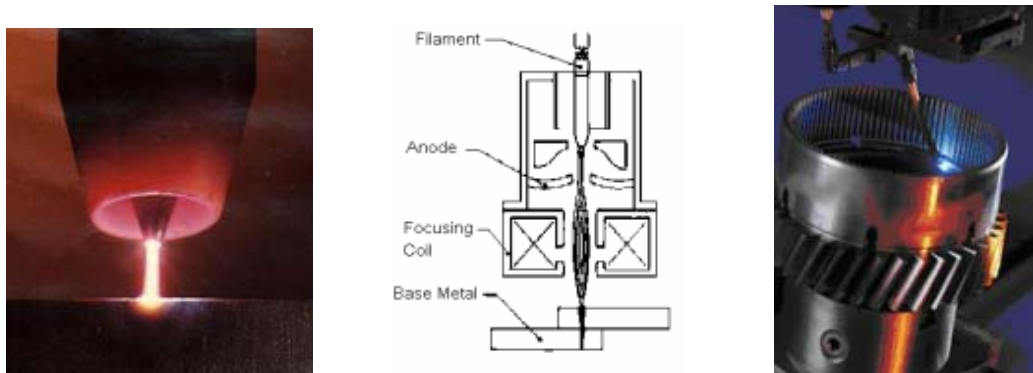


Figure 4 (a) Plasma arc welding (b) Electron Beam Gun making a lap weld (c) Laser welding of a gear

3.2. Solid State Welding

If two parts with very clean surfaces are brought together, the atoms in the lattices at the interface tend to create new bonds across the surfaces – creating a weld. This type of weld does not melt the material, so it is called a solid state weld. Two important properties that facilitate solid state welding are (a) surfaces must be very clean, and (b) high pressure and temperature improve the diffusion process.

3.2.1. Cold welding. This process is useful for joining two dissimilar metals. A common example is seen in rolled sheets that are used to make coins in some countries; another example is construction of bi-metal strips.

3.2.2. Ultrasonic welding. The two components are held together with a static normal force, and a high frequency, low amplitude orthogonal (i.e. shearing) vibration is applied. The vibration causes the surfaces to rub against each other, breaking up all contaminants and oxide layers, and the resulting clean surfaces weld together. The interface temperature in this process reaches maximum of $0.3\sim0.5T_m$ – in other words, there is no melting/fusion.

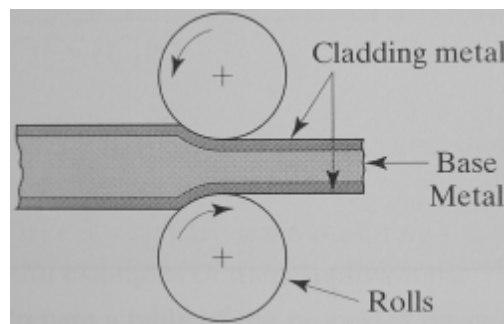


Figure 5. Roll bonding [source: Kalpakjian and Schmid]

3.2.3. Resistance welding. Here, metal strips are welded by holding them together by a force, and raising their temperature by passing a current through the interface. Resistance welding is commonly used in several applications, to make butt joints, lap joints, seam joints etc. Examples include pan-handle welding, automobile mufflers, band-saw blades, seam-joints in automobile bodies and automobile components, etc. Some examples are shown in Figure 6 and Figure 7 below.

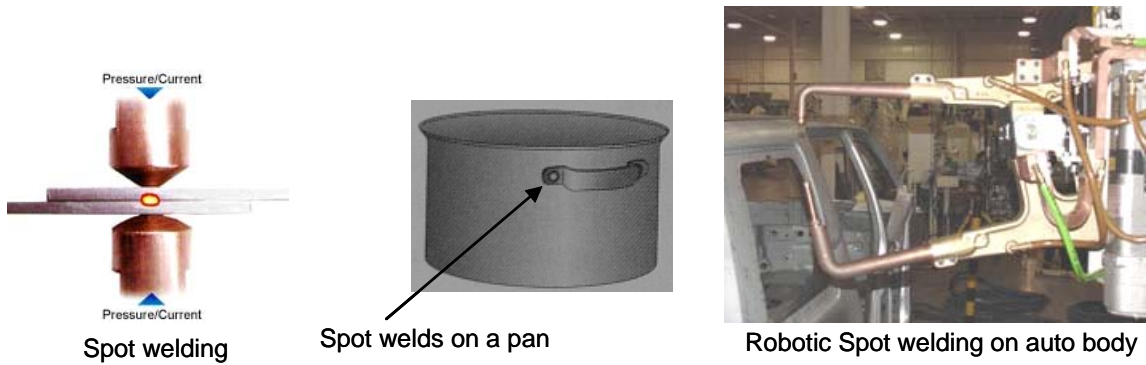


Figure 6. (a) Spot welding (b) and (c) Examples of resistance welding

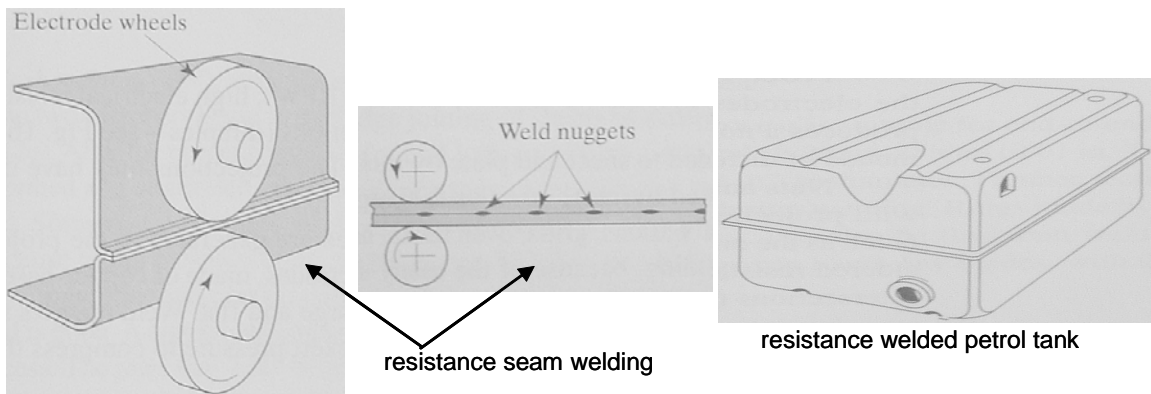


Figure 7. Seam welding (a type of resistance welding) [source: Kalpakjian & Schmid]

3.3. Brazing

In brazing, the filler material is a metal with T_m lower than that of the metals being joint. The filler is placed in the joint (or near it), and the metals are heated till the filler melts (but not the components). The melted filler material fills the joint and, on cooling, creates a brazed joint. In some cases, oxy-acetylene gas welding may be used for this process, with the filler made of a low T_m metal rod. Fluxes are used in brazing, for the same reasons as in welding. In some cases, capillary forces cause the brazing material to flow evenly into the joining interface (see example below).

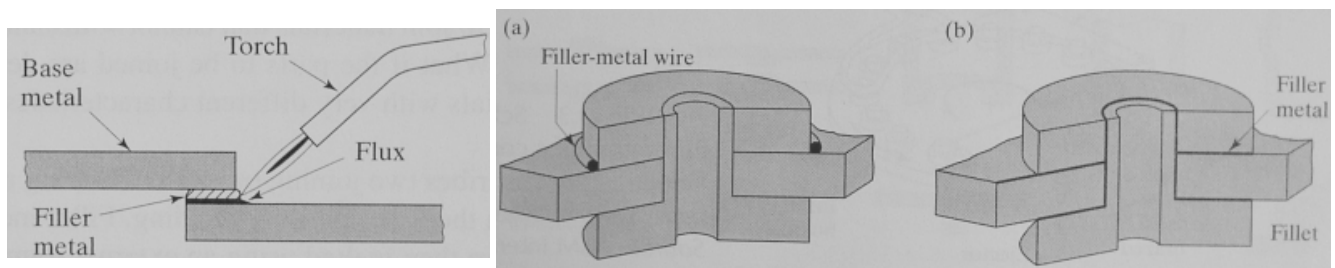


Figure 8. (a) Brazing (b) Furnace brazing [source: Kalpakjian and Schmid]

3.4. Soldering

Solder is a very low T_m metal alloy (Lead + Tin), melting at around 200°C. This is very useful to create joints in electronic circuits, which need not withstand large forces, but should be made with low energy, low temperature processes (why ?). We shall look at different types of soldering when we study electronics manufacturing processes.

3.5. Gluing (Adhesive bonding)

Gluing may be the most common method of joining in different applications. You can see examples of various types of gluing operations in many common products.

Common concerns in the selection of adhesives:

(a) Impact strength (b) Shear strength (c) Peeling/tensile strength (d) Service temperature (d) Curing conditions [aerobic or anaerobic, speed of cure, temperature of curing, UV curing] (e) moisture resistance (f) electrical conductivity (g) toxicity (h) maximum gap size.

The following table lists common adhesive systems, their properties, and uses.

Adhesive type	Notes	Applications
Acrylic	two component thermoplastic; quick setting; impact resistant, strong impact and peel strength	fiberglass, steel, plastics, motor magnets, tennis racquets
Anaerobic	thermoset; slow, no-air curing – cures in presence of metal ions	sealing of nut-and-bolts, close-fitting holes and shafts, casting micro-porosities etc.
Epoxy	strongest adhesive; thermoset; high tensile strength; low peel strength	metal parts (especially Nickel), ceramic parts, rigid plastics
Cyanoacrylate	thermoplastic; high strength; rapid aerobic curing in presence of humidity	[common brand: Crazy glue™] plastics, rubber, ceramics, metals
Hot melt	thermoplastic polymers; rigid or flexible; applied in molten state, cure on cooling	footwear, cartons and other packaging boxes, book-binding
Polyacrylate esters (PSA)	Pressure sensitive adhesives	all types of tapes, labels, stickers, decals, envelops, etc.
Phenolic	thermoset, oven curing, strong but brittle	acoustic padding, brake lining, clutch pads, abrasive grain bonding
Silicone	thermoset, slow curing, flexible	gaskets and sealants
Formaldehyde	thermoset	joining wood, making plywood
Urethane	thermoset, strong at large thickness	fiberglass body parts, concrete gap filling, mold repairs
Water-based	cheap, non-toxic, safe	wood, paper, fabric, leather

3.6. Mechanical Fastening

Mechanical fastening refers to the use of a part or parts that physically limit some or all of the degrees of freedom of a part with respect to another. Below is a list of common fastening methods, and some examples.

- Screws: joining pieces of wood in furniture; pens and mechanical pencils, ...
- Nuts and bolts: Machine components, almost all mechanical products
- Rivets: structural beams in buildings, bridges; airplane bodies, ...
- Staples: holding together sheets of metal, plastic, ...
- Seams: sheet metal joints (e.g. trash cans)...
- Clips: spring clips, o-clips (commonly used in electrical motors to hold shaft in place with respect to housing)
- Snap-fasteners: camera body, electronic toys, caps of containers, etc.



Figure 9. (a) Screws (b) Bolts, nuts and washers (c) Rivets

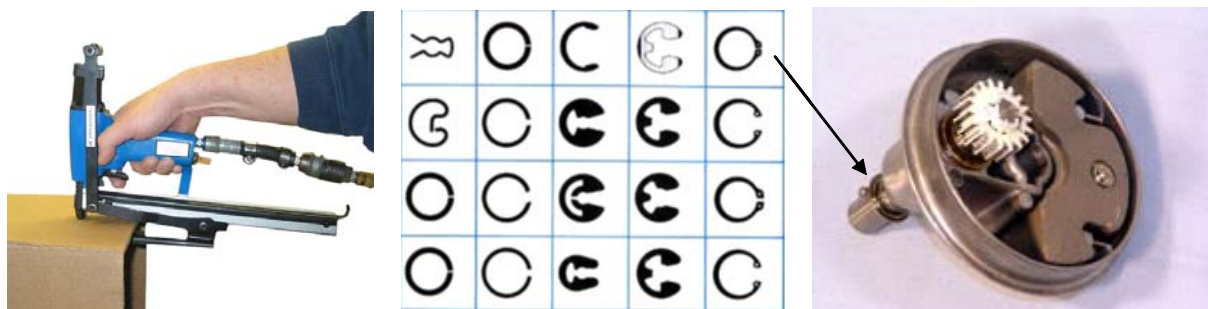


Figure 10. (a) A pneumatic carton stapler (b) Various clips (c) A circlip in the gear drive of a kitchen mixer

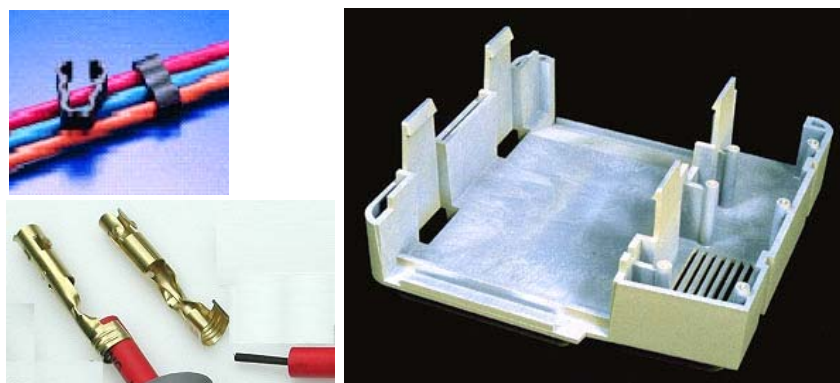


Figure 11. (a) Plastic wire clips (b) Wire is joined to conductor by crimping (c) Plastic snap-fasteners