# 1. CLASSIFICATION OF JOINING METHODS

The three basic options available for assembly and joining of engineering components may be designated:

1. mechanical
2. chemical
3. physical

Some familiar examples:

1. Nailing two pieces of wood together relies on the mechanical frictional forces between the wood and the nail to keep the two pieces of wood in contact at the point of attachment. The pieces are held in place by a balance of mechanical forces, tensile in the nail and compressive in the wood (Fig. 1.1).

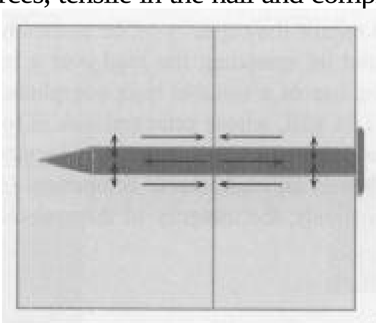

*Fig. 1.1*

*Nailing together two pieces of wood places them in compression, leaving the nail in tension.*

2. A flour and water paste will stick sheets of paper together because the wet flour (starch) swells and penetrates the cellulose fibres of the paper, to form a stiff joint when the excess water evaporates. Hydration of the starch (a chemical reaction) combines with mechanical interlocking of the hardened starch with the cellulose fibres to ensure the mechanical integrity of the bond.

3. An electrical copper contact can be soldered because the flux in the flux-cored solder dissolves the protective oxide film on the copper, allowing molten solder to wet the copper. The solder provides a strong joint because of the strength of the metallic bond which is formed between the (clean) copper substrate and the solder alloy. Copper and the common electrical solders may react to form intermetallic compounds, but these reactions are usually slow. The wetting of the copper and the spreading of the solder are physical processes.

## 1.1 MECHANICAL JOINING METHODS

Mechanical joining methods are often based on localized, point-attachment processes, in which the join is provided by a nail, a rivet, a screw or a bolt. All such joints depend on residual tensile stresses in the attachment to hold the components in compression. The joint is usually formed by an ordered array of point-attachments, as in the equally spaced rivets at the edge of a ship's plate, or the uniformly spaced bolts around a pressure vessel flange.

Mechanical joints are also made along a line of attachment, such as that formed when a piece of sheet is bent to form a cylinder (a paint can, for example) and the two edges are joined with an interlock seam. The complicated sequence of mechanical operations required to form such a seam is illustrated in Fig.

1.2. Here too the residual stresses (tensile around the circumference of the can, compressive along the join) ensure the integrity of the joint.

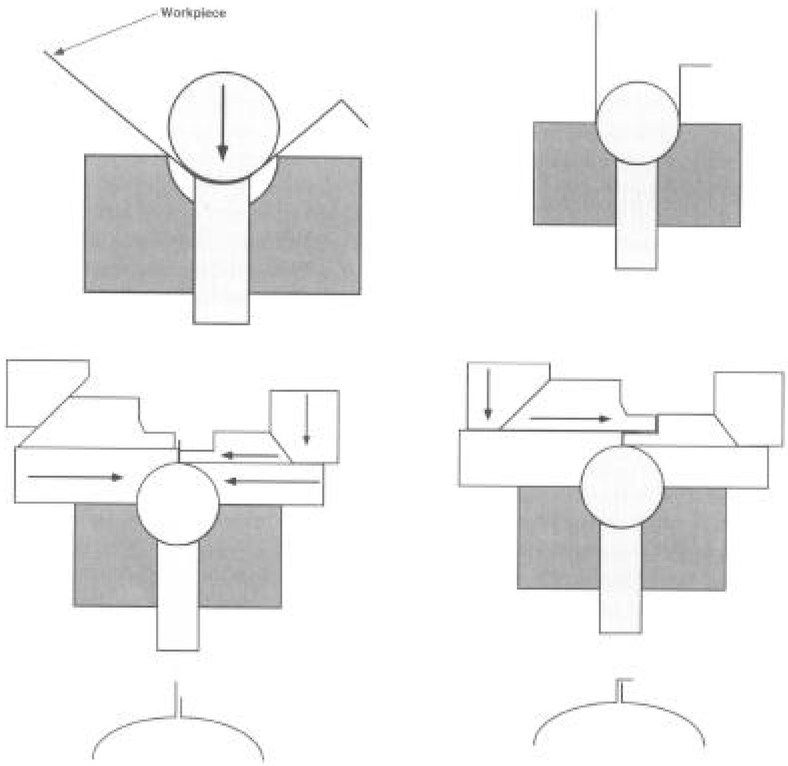


*Fig. 1.2*
*Stages in the formation of an interlock seam.*
*a) The sheet, with a single lip, is formed into a half-cylinder.*
*b) The half-cylinder is clamped in the die.*
*c) The complete cylinder is formed together with the second lip.*
*d) The second lip is turned over the first by 90°.*

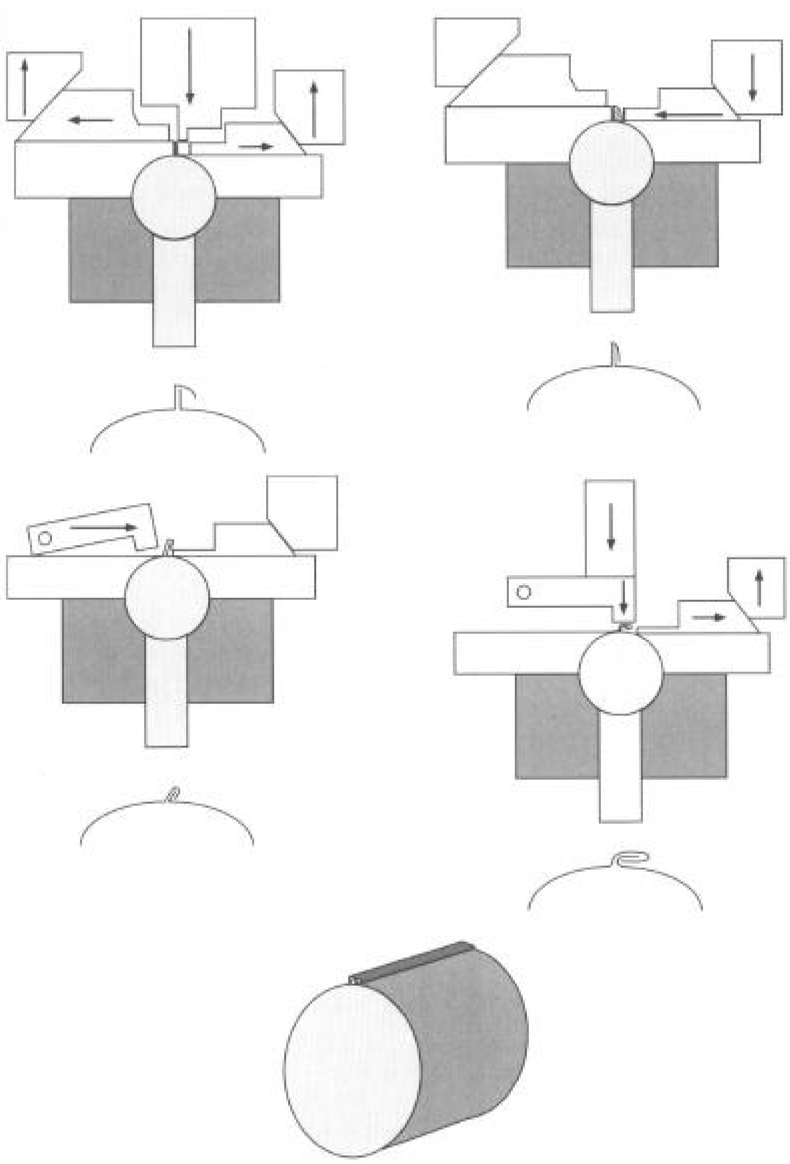

*Fig. 1.2 continued.*
*Stages in the formation of an interlock seam.*
*e)Bending of the second lip over the first is completed.*
*f) The first lip is compressed by the second.*
*g) The sem is bent parallel to the wall of the can.*
*h) The seam is flattened against the can.*
*i) Thefinished seam.*

Many mechanical joints are designed for ease of assembly and disassembly (for example, bolted joints). A demountable joint often depends on frictional forces which exist over a predetermined contact area. A good example would be the ground conical joints which are used to assemble glassware in a chemical laboratory (Fig. 1.3). In this case the presence of a viscous layer of grease between the two surfaces both prevents leakage and aids assembly or disassembly.

### 1.1.1 Role of Residual Stress

Mechanical joints use compressive residual stresses across the join in order to maintain the components in contact. They therefore require a balancing tensile stress elsewhere in the system. These tensile stresses may either be in the fastening (nails, bolts or rivets), or in the components themselves (the interlock seam). Residual tensile stresses generally reduce the capacity of the assembly to carry a tensile load, but they can be minimized by spreading the load over a larger area. This is often accomplished through the use of a suitable high compliance (low rigidity) gasket. Such a gasket also acts as a seal, whose principal task is to ensure that the joint is leak-tight, especially in a point-attachment system. Adequate sealing often depends on the extreme compliance of an elastomeric component (a rubber gasket or elastomeric adhesive). Alternatively, the integrity of the seal may be assured by a wax (applied either from solution or the molten state), an oil or grease (as in the case of the ground glass joint, Fig. 1.3).

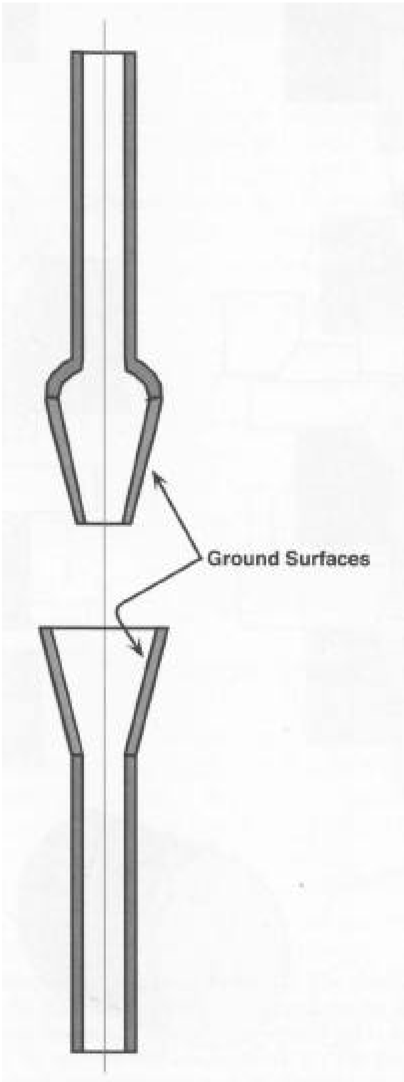


*Fig. 1.3*

*A demountable "cup and cone" ground glass is sealed with a layer of grease.*

## 1.2 CHEMICAL JOINING METHODS

In chemical methods of joining a chemical reaction is employed to achieve the bond. Significant residual stresses may be present in chemical bonded components, but they are usually deleterious, acting to reduce the strength of the bonded joint. Strong adhesives or glues very often depend on the reaction between a liquid precursor and a hardener, which are mixed together before being applied to the joint. A common example is an epoxy resin, which hardens over a period of time after mixing the components. Reaction-based adhesives and glues can be very strong indeed when compared to solvent-based systems, but must be cured by a controlled heating cycle in order to attain their maximum strength. Chemical reactions may be a determining factor in non-polymer bonding systems, for example by modifying the ability to wet the components. The dissolution of copper oxide by a soldering flux is an example of chemical action, and such fluxing reactions are important in most soldering and brazing processes, as well as in welding operations. The successful brazing of ceramic components to metals also requires a wetting reaction between the brazing alloy and the ceramic. An example is the brazing of silicon nitride wear components to alloy steels, in which a copper/silver brazing alloy is used which contains titanium. The titanium in the molten braze reacts with the silicon nitride to form titanium nitride which is then precipitated. This process of reactive brazing results in a brazed contact free of residual porosity.

## 1.3 PHYSICAL JOINING METHODS

Physical methods of joining include all processes based on a phase transition from the liquid to the solid state. Examples would be the use of solvent-based adhesives and glues, as well as welding, brazing and soldering. In addition, we include solid state joining processes, most notably diffusion bonding, as well as transient liquid state processes, in which the transition from liquid to solid is the result of a diffusion-controlled process, rather than a heating and cooling cycle.