Mechanical Assembly

- Mechanical assembly uses various methods to mechanically attach two (or more) parts together.
- In most cases, the method involves the use of discrete hardware components, called fasteners, that are added to the parts during the assembly operation.
- In other cases, the method involves the shaping or reshaping of one of the components being assembled, and no separate fasteners are required.
- Many consumer products are produced using mechanical assembly: automobiles, large and small appliances, telephones, furniture, utensils—even wearing apparel is ‘‘assembled’’ by mechanical means.
- In addition, industrial products such as airplanes, machine tools, and construction equipment almost always involve mechanical assembly.
- Mechanical fastening methods can be divided into two major classes:

(1) those that allow for disassembly, and
(2) those that create a permanent joint.

- Threaded fasteners (e.g., screws, bolts, and nuts) are examples of the first class, and rivets illustrate the second.
- The main reasons to prefer mechanical assembly over other joining processes are:

(1) ease of assembly and
(2) ease of disassembly (for the fastening methods that permit disassembly).

- Mechanical assembly is usually accomplished by unskilled workers with a minimum of special tooling and in a relatively short time.
- The technology is simple, and the results are easily inspected.
- These factors are advantageous not only in the factory, but also during field installation.
- Large products that are too big and heavy to be transported completely assembled can be shipped in smaller subassemblies and then put together at the customer’s site.
- Periodic disassembly is required for many products so that maintenance and repair can be performed; for example, to replace worn-out components, make adjustments, and so forth.
- Permanent joining techniques such as welding do not allow for disassembly.
- For purposes of organization, we divide mechanical assembly methods into the following categories:

(1) threaded fasteners,
(2) rivets,

(3) interference fits,
(4) other mechanical fastening methods, and
(5) molded-in inserts and integral fasteners.

Threaded Fasteners

- Threaded fasteners are discrete hardware components that have external or internal threads for assembly of parts.
- In nearly all cases, they permit disassembly.
- Threaded fasteners are the most important category of mechanical assembly; the common threaded fastener types are screws, bolts, and nuts.

Screws, Bolts, and Nuts

- Screws and bolts are threaded fasteners that have external threads.
- There is a technical distinction between a screw and a bolt that is often blurred in popular usage.
- A screw is an externally threaded fastener that is generally assembled into a blind threaded hole.
- Some types, called self-tapping screws, possess geometries that permit them to form or cut the matching threads in the hole.
- A bolt is an externally threaded fastener that is inserted through holes in the parts and ‘‘screwed’’ into a nut on the opposite side.
- A nut is an internally threaded fastener having standard threads that match those on bolts of the same diameter, pitch, and thread form.
- The typical assemblies that result from the use of screws and bolts are illustrated in Figure (5-57).

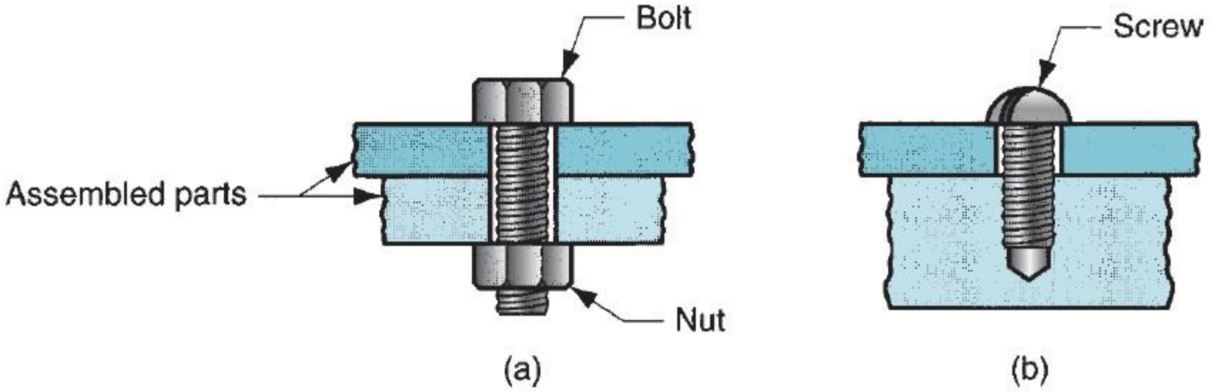

Figure (5-57) Typical assemblies using: (a) bolt and nut, and (b) screw.

- Screws and bolts come in a variety of standard sizes, threads, and shapes according to (ISO standard) and U.S. customary units (ANSI standard).
- ISO: International Standards Organization.
- ANSI: American National Standards Institute.
- The metric specification consists of the nominal major diameter, mm, followed by the pitch, mm.
- For example, a specification of 4-0.7 means a 4.0-mm major diameter and a pitch of 0.7mm.
- The U.S. standard specifies either a number designating the major diameter (up to 0.216 in) or the nominal major diameter, in, followed by the number of threads per inch.
- For example, the specification 1/4-20 indicates a major diameter of 0.25 in and 20 threads per inch.
- Both coarse pitch and fine pitch standards are given in the standards.
- The United States has been gradually converting to metric thread sizes, which will reduce proliferation of specifications.
- It should be noted that differences among threaded fasteners have tooling implications in manufacturing.
- To use a particular type of screw or bolt, the assembly worker must have tools that are designed for that fastener type.
- For example, there are numerous head styles available on bolts and screws, the most common of which are shown in Figure (5-58).

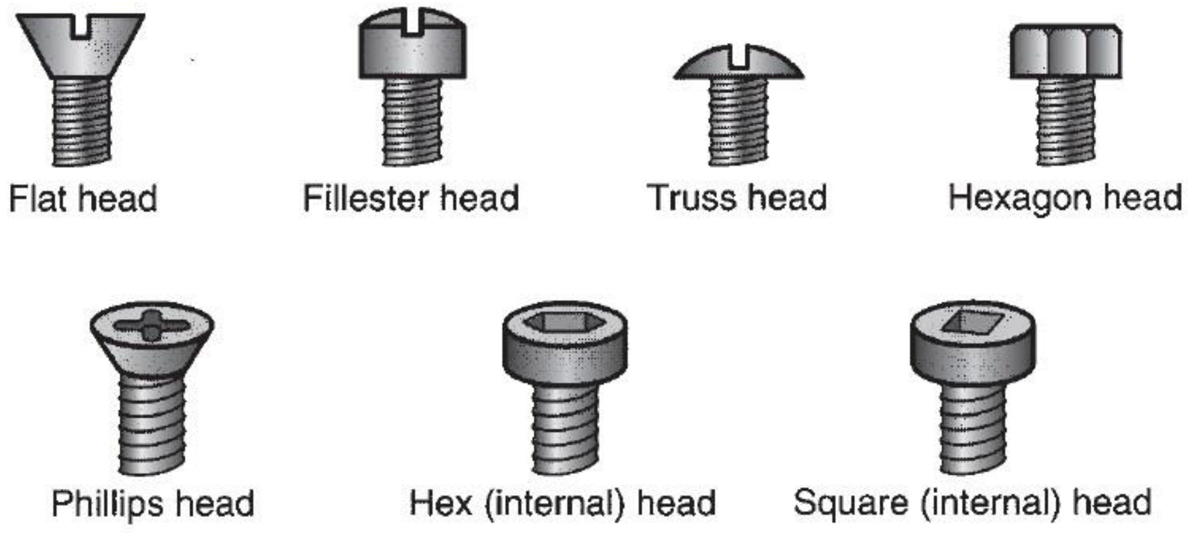

Figure (5-58) Various head styles available on screws and bolts. There are additional head styles not shown.

- The geometries of these heads, as well as the variety of sizes available, require different hand tools (e.g., screwdrivers) for the worker.
- One cannot turn a hex-head bolt with a conventional flat blade screwdriver.
- Screws come in a greater variety of configurations than bolts, since their functions vary more.
- The types include machine screws, cap screws, setscrews, and self-tapping screws.
- Machine screws are the generic type, designed for assembly into tapped holes.
- They are sometimes assembled to nuts, and in this usage they overlap with bolts.
- Cap screws have the same geometry as machine screws but are made of higher strength metals and to closer tolerances.
- Setscrews are hardened and designed for assembly functions such as fastening collars, gears, and pulleys to shafts as shown in Figure (5-59a).
- They come in various geometries, some of which are illustrated in Figure (5-59b).

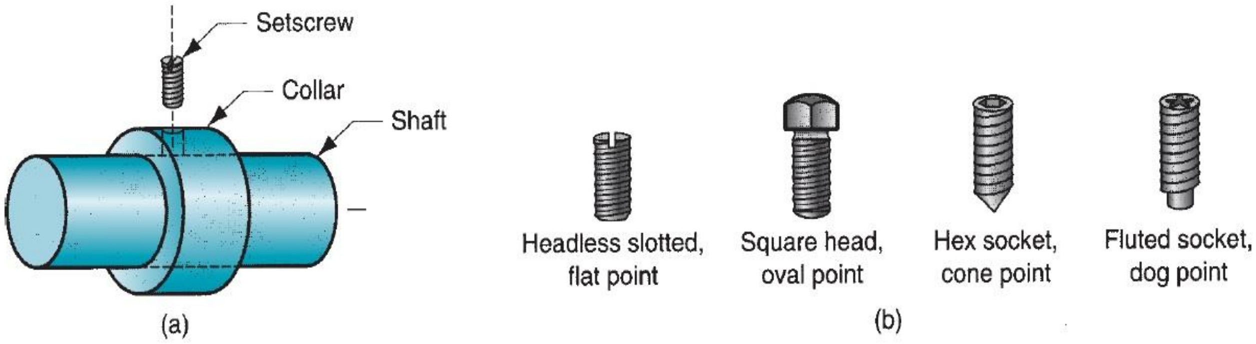

Figure (5-59) (a) Assembly of collar to shaft using a setscrew; (b) various setscrew geometries (head types and points).

- A self-tapping screw (also called a tapping screw) is designed to form or cut threads in a preexisting hole into which it is being turned.
- Figure (5-60) shows two of the typical thread geometries for self-tapping screws.

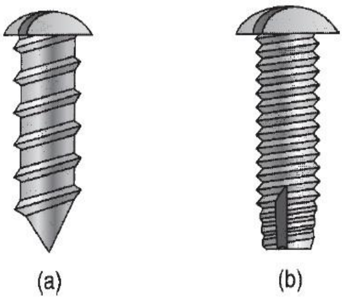

Figure (5-60) Self-tapping screws: (a) thread-forming and (b) thread-cutting.

- Most threaded fasteners are produced by cold forming.
- Some are machined, but this is usually a more expensive thread making process.
- A variety of materials are used to make threaded fasteners, steels being the most common because of their good strength and low cost.
- These include low and medium carbon as well as alloy steels.
- Fasteners made of steel are usually plated or coated for superficial resistance to corrosion.
- Nickel, chromium, zinc, black oxide, and similar coatings are used for this purpose.
- When corrosion or other factors deny the use of steel fasteners, other materials must be used, including stainless steels, aluminum alloys, nickel alloys, and plastics (however, plastics are suited to low stress applications only).

Other Threaded Fasteners and Related Hardware

- Additional threaded fasteners and related hardware include studs, screw thread inserts, captive threaded fasteners, and washers.
- A stud (in the context of fasteners) is an externally threaded fastener, but without the usual head possessed by a bolt.
- Studs can be used to assemble two parts using two nuts as shown in Figure (5-61a).
- They are available with threads on one end or both as in Figure (5-61b) and (c).

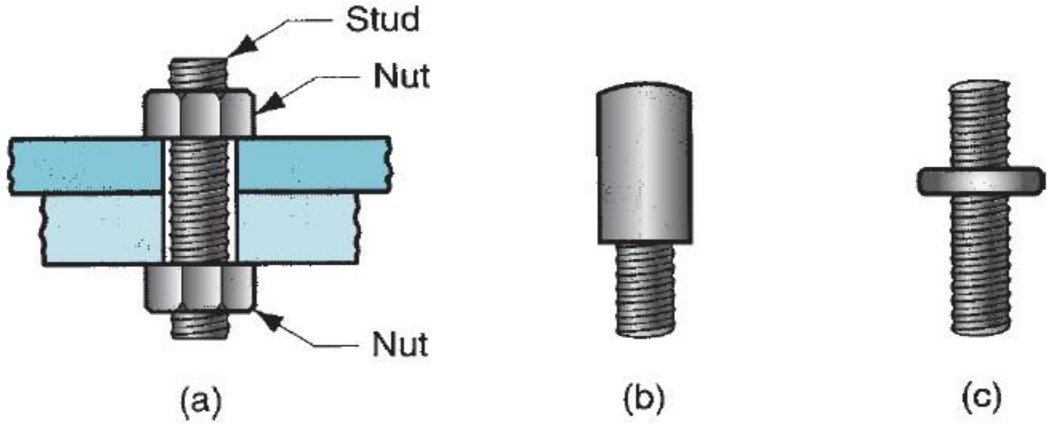

Figure (5-61) (a) Stud and nuts used for assembly. Other stud types: (b)threads on one end only and (c) double-end stud.

- Screw thread inserts are internally threaded plugs or wire coils made to be inserted into an unthreaded hole and to accept an externally threaded fastener.
- They are assembled into weaker materials (e.g., plastic, wood, and light-weight metals such as magnesium) to provide strong threads.
- There are many designs of screw thread inserts, one example of which is illustrated in Figure (5-62).

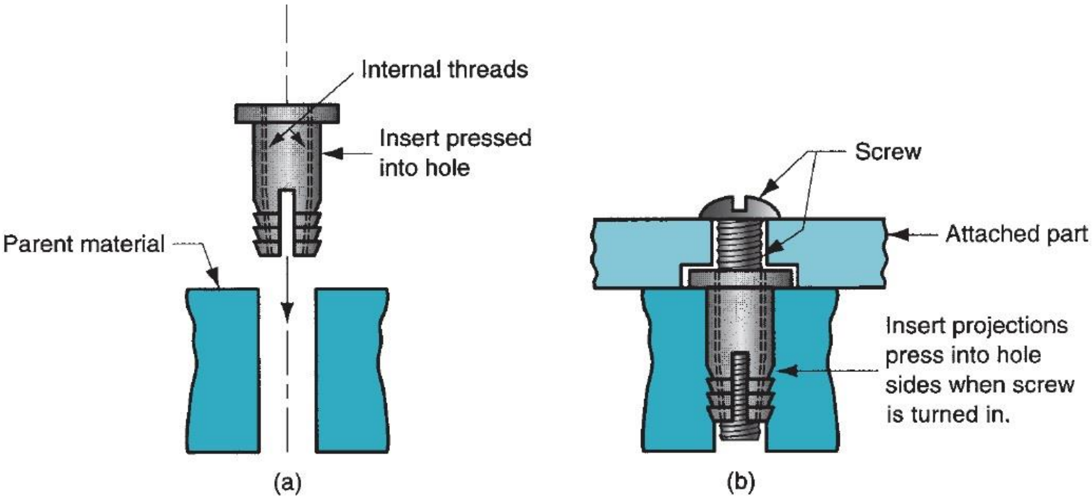

Figure (5-62) Screw thread inserts: (a) before insertion, and (b) after insertion into hole and screw is turned into the insert.

- Upon subsequent assembly of the screw into the insert, the insert barrel expands into the sides of the hole, securing the assembly.
- Captive threaded fasteners are threaded fasteners that have been permanently preassembled to one of the parts to be joined.
- Possible preassembly processes include welding, brazing, press fitting, or cold forming.
- Two types of captive threaded fasteners are illustrated in Figure (5-63).

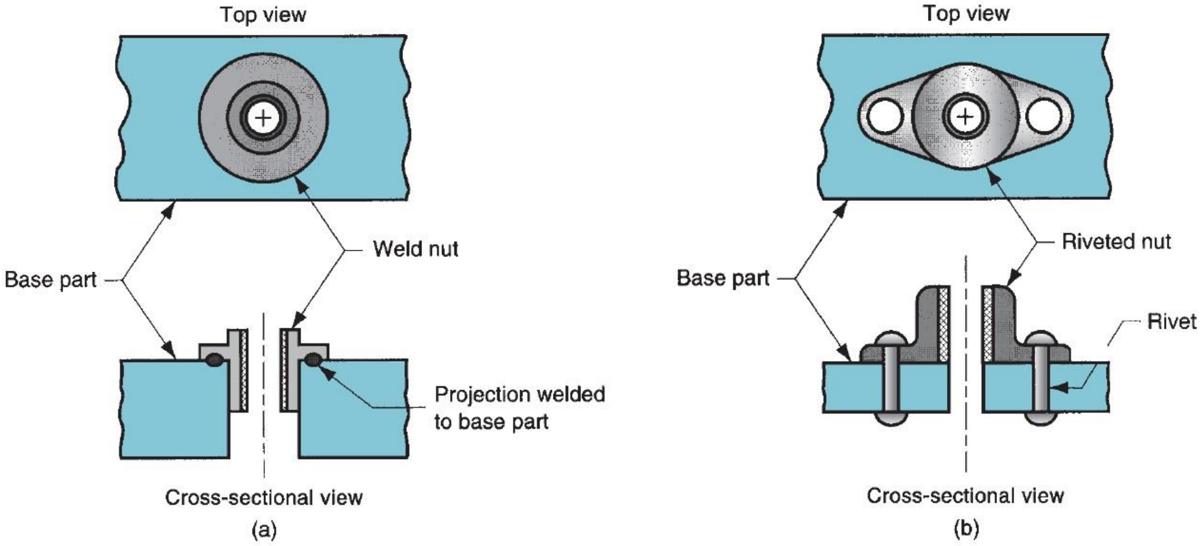

Figure (5-63) Captive threaded fasteners: (a) weld nut and (b) riveted nut.

- A washer is a hardware component often used with threaded fasteners to ensure tightness of the mechanical joint; in its simplest form, it is a flat thin ring of sheet metal.
- Washers serve various functions:

(1) distribute stresses that might otherwise be concentrated at the bolt or screw head and nut,
(2) provide support for large clearance holes in the assembled parts,
(3) increase spring tension,
(4) protect part surfaces,
(5) seal the joint, and
(6) resist inadvertent unfastening.

- Three washer types are illustrated in Figure (5-64).

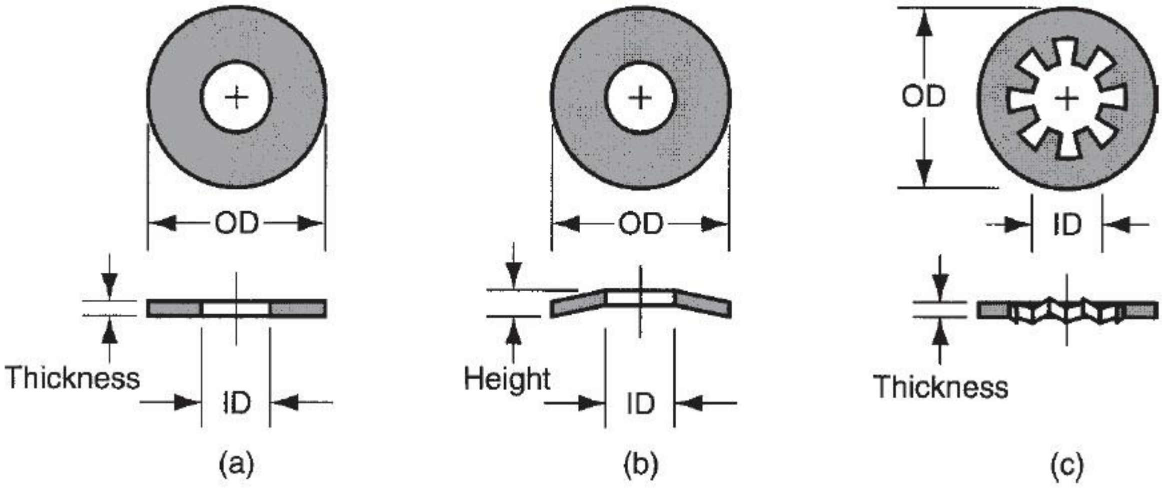

Figure (5-64) Types of washers: (a) plain (flat) washers; (b) spring washers, used to dampen vibration or compensate for wear; and (c) lockwasher designed to resist loosening of the bolt or screw.

Stresses and strengths in Bolted Joints

- Typical stresses acting on a bolted or screwed joint include both tensile and shear, as depicted in Figure (5-65).
- Shown in the figure is a bolt-and-nut assembly.
- Once tightened, the bolt is loaded in tension, and the parts are loaded in compression.
- In addition, forces may be acting in opposite directions on the parts, which results in a shear stress on the bolt cross section.

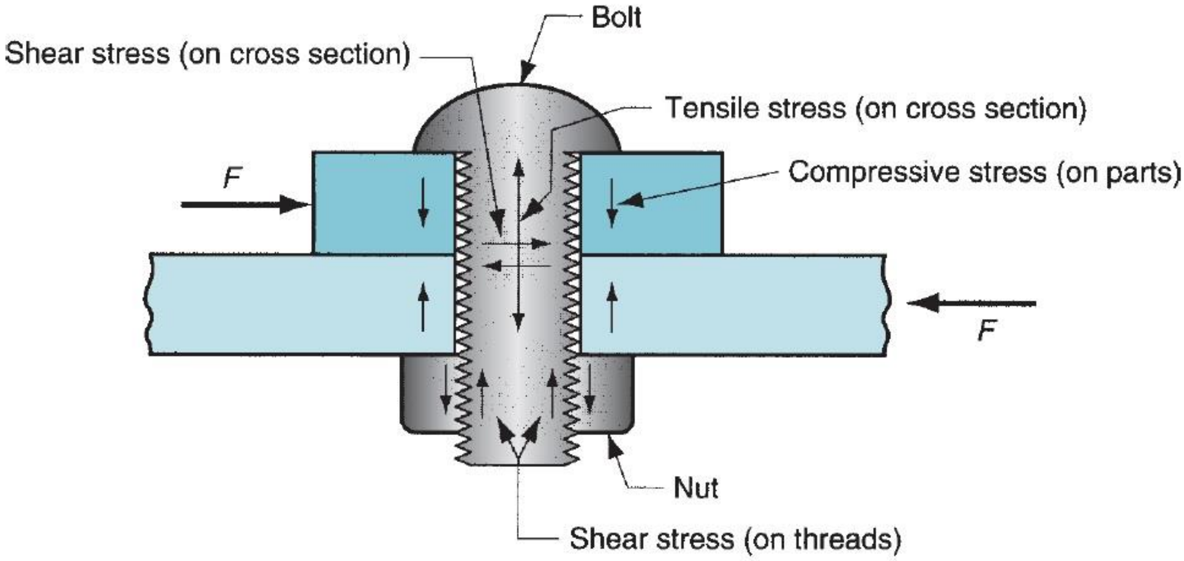

Figure (5-65) Typical stresses acting on a bolted joint.

- Finally, there are stresses applied on the threads throughout their engagement length with the nut in a direction parallel to the axis of the bolt.
- These shear stresses can cause stripping of the threads.
- This failure can also occur on the internal threads of the nut.
- The strength of a threaded fastener is generally specified by two measures:

(1) tensile strength, which has the traditional definition, and
(2) proof strength.

- Proof strength is roughly equivalent to yield strength; specifically, it is the maximum tensile stress to which an externally threaded fastener can be subjected without permanent deformation.
- The problem that can arise during assembly is that the threaded fasteners are overtightened, causing stresses that exceed the strength of the fastener material.
- Assuming a bolt-and-nut assembly as shown in Figure (5-65), failure can occur in one of the following ways:

(1) external threads (e.g., bolt or screw) can strip,
(2) internal threads (e.g., nut) can strip, or
(3) the bolt can break because of excessive tensile stresses on its cross-sectional area.

- Thread stripping, failures (1) and (2), is a shear failure and occurs when the length of engagement is too short (less than about 60% of the nominal bolt diameter).
- This can be avoided by providing adequate thread engagement in the fastener design.
- Tensile failure (3) is the most common problem.
- The bolt breaks at about 85% of its rated tensile strength because of combined tensile and torsion stresses during tightening.

- The tensile stress to which a bolt is subjected can be calculated as the tensile load applied to the joint divided by the applicable area:

$$\sigma = \frac{F}{A_s}$$

σ: stress, MP_a,
F: load, N,
A_s: tensile stress area, mm^2.

- This stress is compared to the bolt strength values listed in standard tables.
- The tensile stress area for a threaded fastener is the cross-sectional area of the minor diameter.
- This area can be calculated directly from one of the following equations, depending on whether the bolt is metric standard or American standard.
- For the metric standard (ISO), the formula is:

$$A_s = \frac{\pi}{4}(D - 0.9382p)^2$$

D: nominal size (basic major diameter) of the bolt or screw, mm;
p: thread pitch, mm.

- For the American standard (ANSI), the formula is:

$$A_s = \frac{\pi}{4}\left(D - \frac{0.9743}{n}\right)^2$$

D: nominal size (basic major diameter) of the bolt or screw, in;
n: the number of threads per inch.

Tools and Methods for Threaded Fasteners

- The basic function of the tools and methods for assembling threaded fasteners is: (1) to provide relative rotation between the external and internal threads, and (2) to apply sufficient torque to secure the assembly.
- Available tools range from simple hand-held screwdrivers or wrenches to powered tools with sophisticated electronic sensors to ensure proper tightening.
- It is important that the tool match the screw or bolt and/or the nut in style and size, since there are so many heads available.
- Hand tools are usually made with a single point or blade, but powered tools are generally designed to use interchangeable bits.
- The powered tools operate by pneumatic, hydraulic, or electric power.
- Whether a threaded fastener serves its intended purpose depends to a large degree on the amount of torque applied to tighten it.
- Once the bolt or screw (or nut) has been rotated until it is seated against the part surface, additional tightening will increase the tension in the fastener (and simultaneously the compression in the parts being held together); and the tightening will be resisted by an increasing torque.
- Thus, there is a correlation between the torque required to tighten the fastener and the tensile stress experienced by it.
- To achieve the desired function in the assembled joint (e.g., to improve fatigue resistance) and to lock the threaded fasteners, the product designer will often specify the tension force that should be applied.
- This force is called the preload.
- The following relationship can be used to determine the required torque to obtain a specified preload:

$$\boldsymbol{T = C_t D F}\mathrm{T}$$

T : torque, N-mm (lb-in);
C_t: the torque coefficient whose value typically ranges between 0.15 and 0.25, depending on the thread surface conditions;
D: nominal bolt or screw diameter, mm (in);
F: specified preload tension force, N (lb).

- Various methods are employed to apply the required torque, including
(1) operator feel—not very accurate, but adequate for most assemblies;
(2) torque wrenches, which measure the torque as the fastener is being turned;
(3) stall-motors, which are motorized wrenches designed to stall when the required torque is reached,

(4) torque-turn tightening, in which the fastener is initially tightened to a low torque level and then rotated a specified additional amount (e.g., a quarter turn).

Rivets and Eyelets

- Rivets are widely used for achieving a permanent mechanically fastened joint.
- Riveting is a fastening method that offers high production rates, simplicity, dependability, and low cost.
- Despite these apparent advantages, its applications have declined in recent decades in favor of threaded fasteners, welding, and adhesive bonding.
- Riveting is one of the primary fastening processes in the aircraft and aerospace industries for joining skins to channels and other structural members.
- A rivet is an unthreaded, headed pin used to join two (or more) parts by passing the pin through holes in the parts and then forming (upsetting) a second head in the pin on the opposite side.
- The deforming operation can be performed hot or cold (hot working or cold working), and by hammering or steady pressing.
- Once the rivet has been deformed, it cannot be removed except by breaking one of the heads.
- Rivets are specified by their length, diameter, head, and type.
- Rivet type refers to five basic geometries that affect how the rivet will be upset to form the second head.
- The five types are defined in Figure (5-66).
- In addition, there are special rivets for special applications.

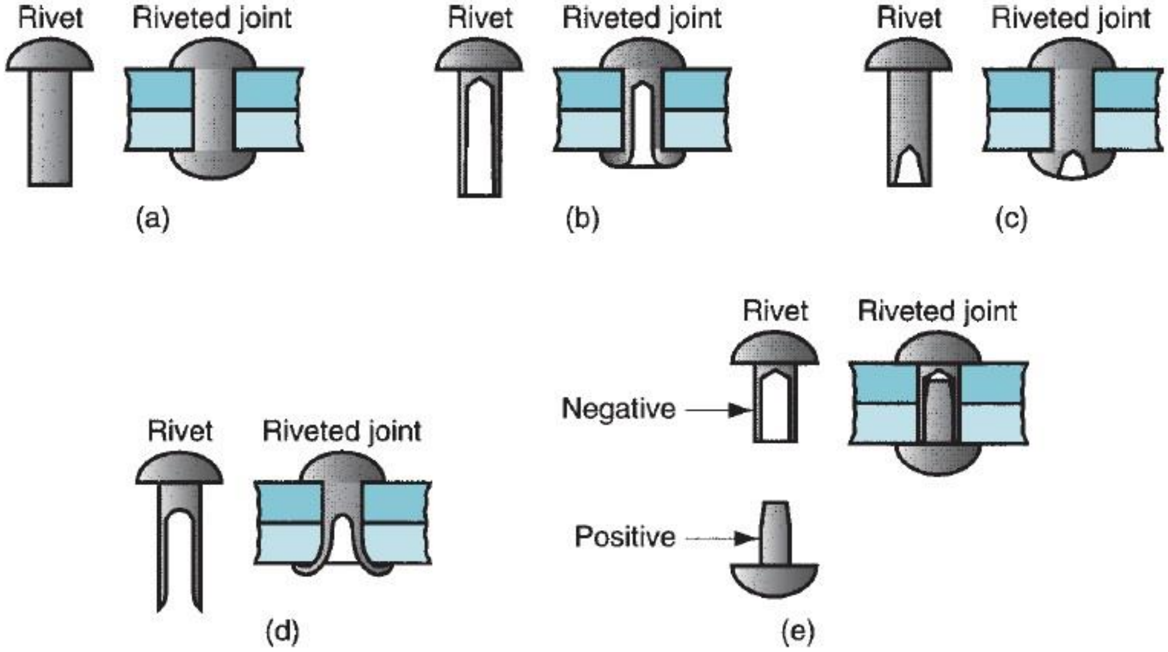

Figure (5-66) Five basic rivet types, also shown in assembled configuration: (a) solid, (b) tubular, (c) semi-tubular,(d)bifurcated, and (e) compression.

- Rivets are used primarily for lap joints.
- The clearance hole into which the rivet is inserted must be close to the diameter of the rivet.
- If the hole is too small, rivet insertion will be difficult, thus reducing production rate.
- If the hole is too large, the rivet will not fill the hole and may bend or compress during formation of the opposite head.
- Rivet design tables are available to specify the optimum hole sizes.
- The tooling and methods used in riveting can be divided into the following categories:

(1) impact, in which a pneumatic hammer delivers a succession of blows to upset the rivet;
(2) steady compression, in which the riveting tool applies a continuous squeezing pressure to upset the rivet; and
(3) a combination of impact and compression.

- Much of the equipment used in riveting is portable and manually operated.
- Automatic drilling-and-riveting machines are available for drilling the holes and then inserting and upsetting the rivets.

- **Eyelets** are thin-walled tubular fasteners with a flange on one end, usually made from sheet metal, as in Figure (5-67a).

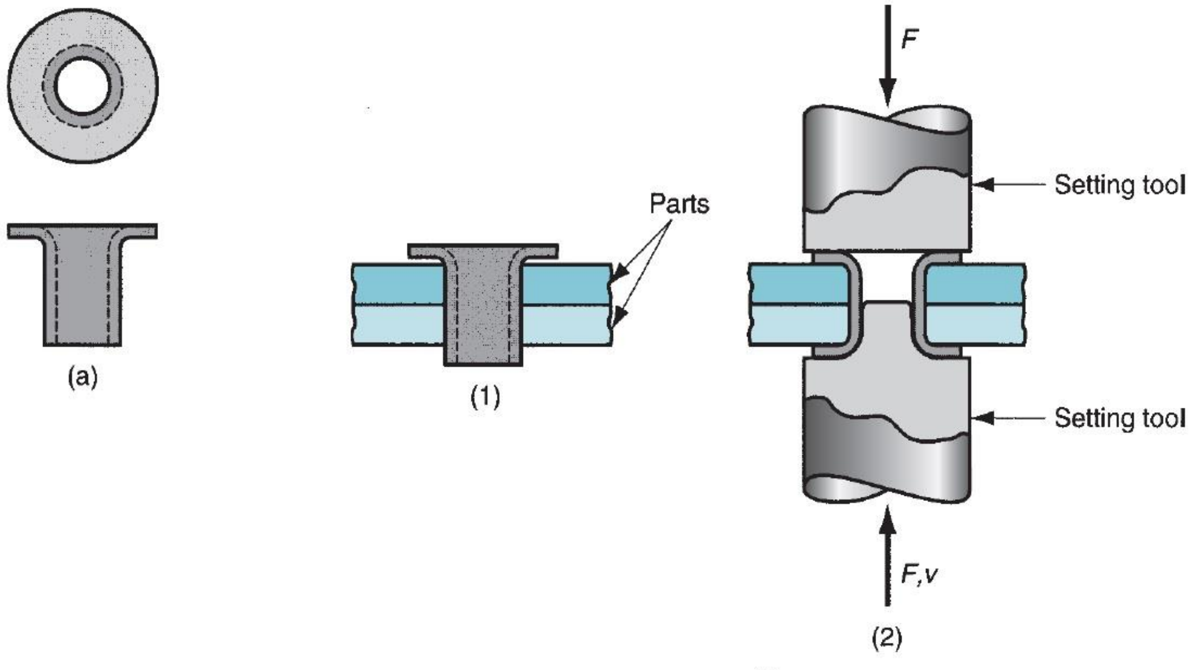

Figure (5-67) Fastening with an eyelet: (a) the eyelet, and (b) assembly sequence: (1) inserting the eyelet through the hole and (2) setting operation.

- **Eyelets** are used to produce a permanent lap joint between two (or more) flat parts.
- **Eyelets** are substituted for rivets in low-stress applications to save material, weight, and cost.
- During fastening, the eyelet is inserted through the part holes, and the straight end is formed over to secure the assembly.
- The forming operation is called setting and is performed by opposing tools that hold the eyelet in position and curl the extended portion of its barrel.
- Figure (5-67b) illustrates the sequence for a typical eyelet design.
- **Applications of this fastening method include automotive subassemblies, electrical components, toys, and apparel.**

Assembly Methods Based on Interference Fits

- Several assembly methods are based on mechanical interference (either during assembly or after the parts are joined) between the two mating parts being joined.
- The methods include:
  (a) Press Fitting
  (b) Shrink and Expansion Fits
  (c) Snap Fits and Retaining Rings

(a) Press Fitting

- A press fit assembly is one in which the two components have an interference fit between them.
- The typical case is where a pin (e.g., a straight cylindrical pin) of a certain diameter is pressed into a hole of a slightly smaller diameter.

- **Functions of Standard Pins:**

(1) locating and locking the components—used to augment threaded fasteners by holding two (or more) parts in fixed alignment with each other (normally hardened);

(2) pivot points, to permit rotation of one component about the other (normally hardened);

(3) shear pins (made of softer metals so as to break under a sudden or severe shearing load to save the rest of the assembly).

- **Applications of press fitting include assembly of collars, gears, pulleys, and similar components onto shafts.**
- The pressures and stresses in an interference fit can be estimated using several applicable formulas.
- If the fit consists of a round solid pin or shaft inside a collar (or similar component), as depicted in Figure (5-68), and the components are made of the same material, the radial pressure between the pin and the collar can be determined by:

$$p_f = \frac{Ei\left(D_c^2 - D_p^2\right)}{D_p D_c^2}$$

Where:

p_f : radial or interference fit pressure, MPa (lb/in^2);

E: modulus of elasticity for the material;

I: interference between the pin (or shaft) and the collar; that is, the starting difference between the inside diameter of the collar hole and the outside diameter of the pin, mm (in);

D_c: outside diameter of the collar, mm (in);

D_p: pin or shaft diameter, mm (in).

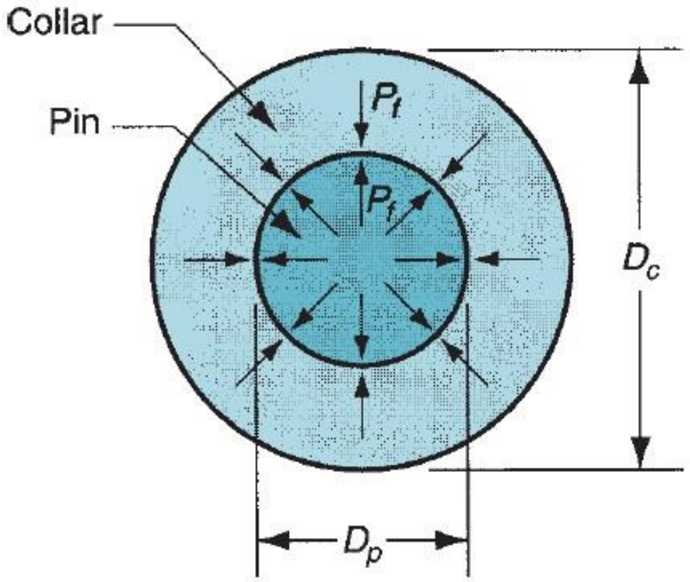

Figure (5-68) Cross section of a solid pin or shaft assembled to a collar by interference fit.

- The maximum effective stress occurs in the collar at its inside diameter and can be calculated as:

$$Max\ \sigma_e = \frac{2p_f D_c^2}{D_c^2 - D_p^2}$$

Where:

Max σ_e**:** the maximum effective stress, MPa (lb/in2),

p_f: is the interference fit pressure computed from above p_f equation.

- In situations in which a straight pin or shaft is pressed into the hole of a large part with geometry other than that of a collar, we can take the outside diameter D_c to be infinite, thus the p_f:

$$p_f = \frac{Ei}{D_p}$$

and the corresponding maximum effective stress becomes:

$$Max\ \sigma_e = 2p_f$$

- In most cases, particularly for ductile metals, the maximum effective stress should be compared with the yield strength of the material, applying an appropriate safety factor, as in the following:

$$Max\ \sigma_e \leq \frac{Y}{SF}$$

Where:

Y : yield strength of the material,

SF: the applicable safety factor.

- Various pin geometries are available for interference fits.
- **Straight Pin**, usually made from cold-drawn carbon steel wire or bar stock, ranging in diameter from 1.6 to 25 mm.
- They are unground, with chamfered or square ends (chamfered ends facilitate press fitting).
- **Dowel Pins** are manufactured to more precise specifications than straight pins, and can be ground and hardened.
- They are used to fix the alignment of assembled components in dies, fixtures, and machinery.
- **Taper Pins** possess a taper of 6.4mm per foot and are driven into the hole to establish a fixed relative position between the parts.
- Their advantage is that they can readily be driven back out of the hole.
- **Grooved Pins**, solid straight pins with three longitudinal grooves in which the metal is raised on either side of each groove to cause interference when the pin is pressed into a hole.
- **Knurled Pins**, pins with a knurled pattern that causes interference in the mating hole.
- **Coiled Pins (Spiral Pins)**, which are made by rolling strip stock into a coiled spring.

(b) Shrink and Expansion Fits

- These terms refer to the assembly of two parts that have an interference fit at room temperature.
- The typical case is a cylindrical pin or shaft assembled into a collar.
- To assemble by **shrink fitting**, the external part is heated to enlarge it by thermal expansion, and the internal part either remains at room temperature or is cooled to contract its size.
- The parts are then assembled and brought back to room temperature, so that the external part shrinks, and if previously cooled the internal part expands, to form a strong interference fit.
- An **expansion fit** is when only the internal part is cooled to contract it for assembly; once inserted into the mating component, it warms to room temperature, expanding to create the interference assembly.
- These assembly methods are used to fit gears, pulleys, sleeves, and other components onto solid and hollow shafts.
- Various methods are used to heat and/or cool the w.ps.
- Heating equipment includes torches, furnaces, electric resistance heaters, and electric induction heaters.
- Cooling methods include conventional refrigeration, packing in dry ice, and immersion in cold liquids, including liquid nitrogen.
- The resulting change in diameter depends on the coefficient of thermal expansion and the temperature difference that is applied to the w.p.

- The change in diameter is given by

$$\boldsymbol{D_2 - D_1 = \alpha D_1 (T_2 - T_1)}$$

(If heating or cooling has produced a uniform temperature throughout w.p.)

Where:

α: the coefficient of linear thermal expansion, mm/mm-° C (in/in-° F) for the material.

T_2: the temperature to which the w.p. have been heated or cooled, °C (°F).

T_1: starting ambient temperature.

D_2: diameter of the w.p. at T_2, mm (in).

D_1: diameter of the w.p. at T_1.

Note: The above equations for rivets and eyelets for computing interference pressures and effective stresses can be used to determine the corresponding values for shrink and expansion fits.

(c) Snap Fits and Retaining Rings

- They are a variation of interference fits.
- **A snap fit** involves joining two parts in which the mating elements possess a temporary interference while being pressed together, but once assembled they interlock to maintain the assembly.
- A typical example is shown in Figure (5-69): as the parts are pressed together, the mating elements elastically deform to accommodate the interference, subsequently allowing the parts to snap together; once in position, the elements become connected mechanically so that they cannot easily be disassembled.

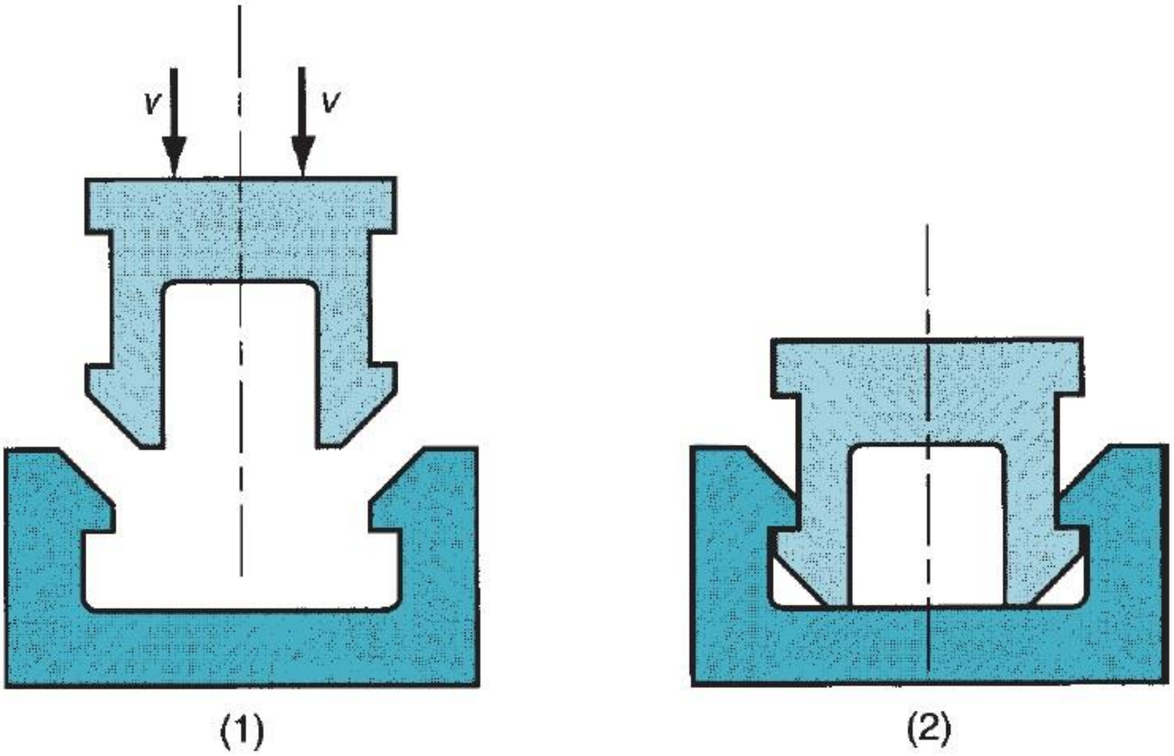

Figure (5-69) Snap fit assembly, showing cross sections of two mating parts: (1) before assembly and (2) parts snapped together.

- **Advantages of snap fit assembly include**:
  (1) the parts can be designed with self-aligning features,
  (2) no special tooling is required,
  (3) assembly can be accomplished very quickly.

- **A retaining ring**, also known as **a snap ring**, is a fastener that snaps into a circumferential groove on a shaft or tube to form a shoulder, as in Figure (5-70).
- The assembly can be used to locate or restrict the movement of parts mounted on the shaft.
- Retaining rings are available for both external (shaft) and internal (bore) applications.
- They are made from either sheet metal or wire stock, heat treated for hardness and stiffness.

- To assemble a retaining ring, a special pliers tool is used to elastically deform the ring so that it fits over the shaft (or into the bore) and then is released into the groove.

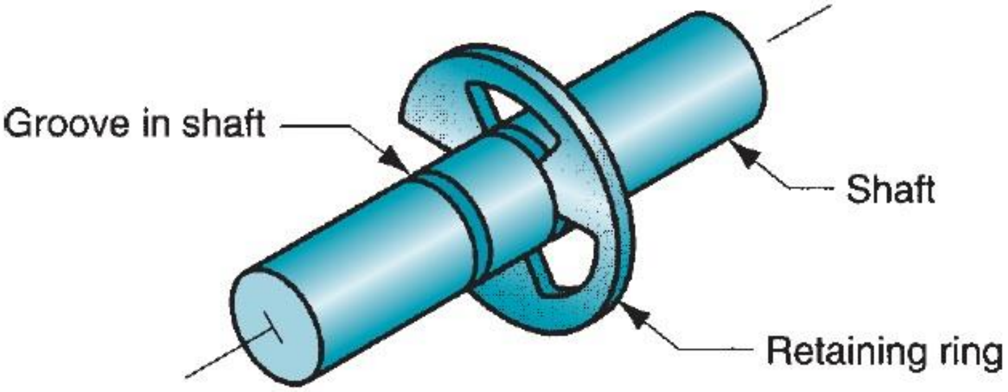

Figure (5-70) Retaining ring assembled into a groove on a shaft.