Adhesive Bonding

- Adhesive bonding is a joining process in which a filler material is used to hold two (or more) closely spaced parts together by surface attachment.
- The filler material that binds the parts together is the adhesive.
- It is a nonmetallic substance—usually a polymer.
- The parts being joined are called adherends.
- Adhesives of greatest interest in engineering are structural adhesives, which are capable of forming strong, permanent joints between strong, rigid adherends.
- A large number of adhesives are cured by various mechanisms.
- Curing refers to the process by which the adhesive's physical properties are changed from a liquid to a solid, usually by chemical reaction, to accomplish the surface attachment of the parts.
- The chemical reaction may involve polymerization, condensation, or vulcanization.
- Curing is often motivated by heat and/or a catalyst, and pressure is sometimes applied between the two parts to activate the bonding process.
- If heat is required, the curing temperatures are relatively low, and so the materials being joined are usually unaffected—an advantage for adhesive bonding.
- The curing or hardening of the adhesive takes time, called curing time or setting time.
- In some cases this time is significant—generally a disadvantage in manufacturing.
- **Joint strength in adhesive bonding is determined by** (1) the strength of the adhesive itself and (2) the strength of attachment between adhesive and each of the adherends.
- **One of the criteria often used to define a satisfactory adhesive joint is that if a failure should occur due to excessive stresses, it occurs in one of the adherends rather than at an interface or within the adhesive itself.**
- The strength of the attachment results from several mechanisms, all depending on the particular adhesive and adherends:

(1) chemical bonding, in which the adhesive unites with the adherends and forms a primary chemical bond upon hardening;

(2) physical interactions, in which secondary bonding forces result between the atoms of the opposing surfaces; and

(3) mechanical interlocking, in which the surface roughness of the adherend causes the hardened adhesive to become entangled or trapped in its microscopic surface asperities.

- For these adhesion mechanisms to operate with best results, the following conditions must prevail:

(1) surfaces of the adherend must be clean—free of dirt, oil, and oxide films that would interfere with achieving intimate contact between adhesive and adherend; special preparation of the surfaces is often required;

(2) the adhesive in its initial liquid form must achieve thorough wetting of the adherend surface; and

(3) it is usually helpful for the surfaces to be other than perfectly smooth—a slightly roughened surface increases the effective contact area and promotes mechanical interlocking.

(4) In addition, the joint must be designed to exploit the particular strengths of adhesive bonding and avoid its limitations.

Joint Design

- Adhesive joints are not generally as strong as those by welding, brazing, or soldering.
- Accordingly, consideration must be given to the design of joints that are adhesively bonded.
- The following design principles are applicable:

(1) Joint contact area should be maximized.

(2) Adhesive joints are strongest in shear and tension as in Figure (5-53a) and (5-52b), and joints should be designed so that the applied stresses are of these types.

(3) Adhesive bonded joints are weakest in cleavage or peeling as in Figure (5-52c) and (5-52d), and adhesive bonded joints should be designed to avoid these types of stresses.

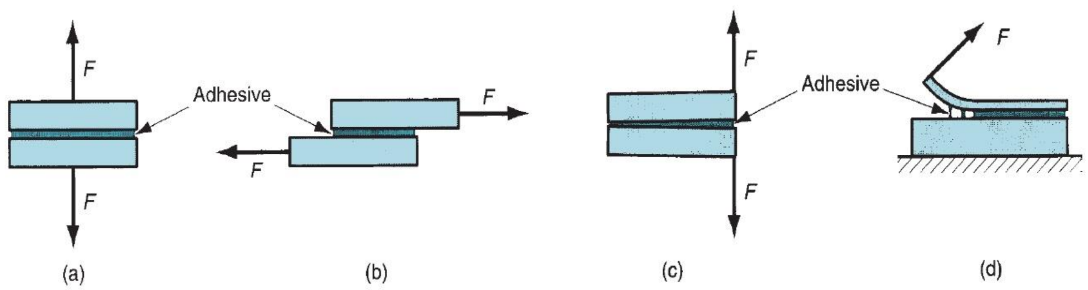

Figure (5-52) Types of stresses that must be considered in adhesive bonded joints: (a) tension, (b) shear, (c) cleavage, and (d) peeling.

- Typical joint designs for adhesive bonding that illustrate these design principles are presented in Figure (5-53).

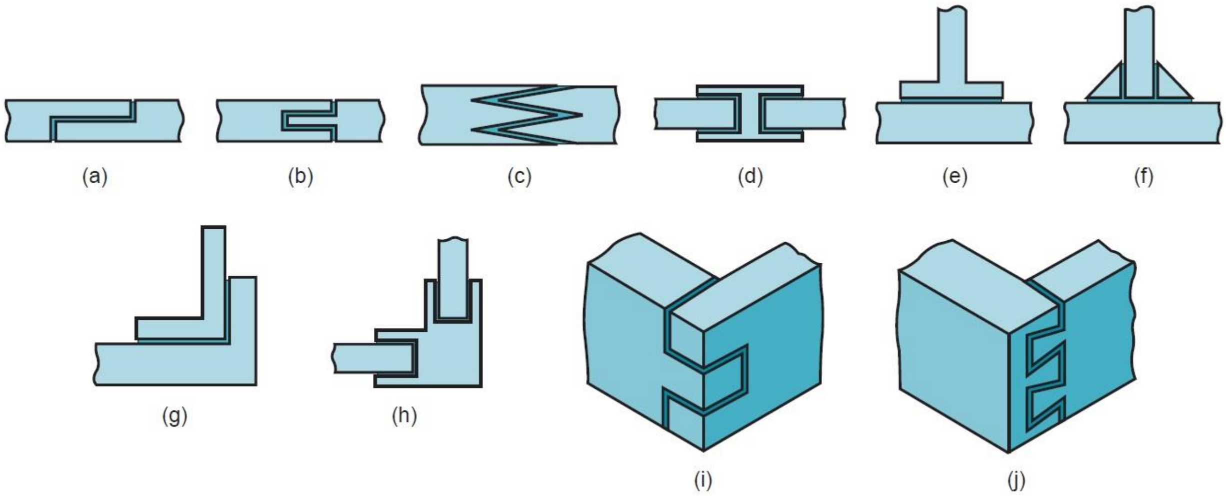

Figure (5-53) Some joint designs for adhesive bonding: (a) through (d) butt joints; (e) and (f) T-joints; and (g) through (j) corner joints.

- Some joint designs combine adhesive bonding with other joining methods to increase strength and/or provide sealing between the two components.
- Some of the possibilities are shown in Figure (5-54).

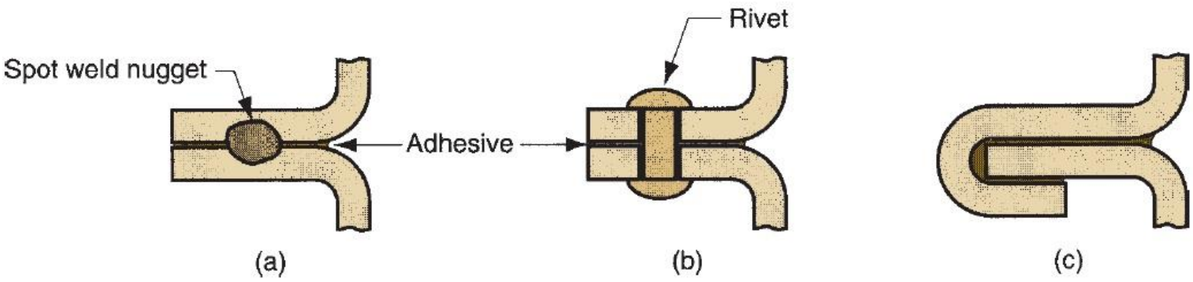

Figure (5-54) Adhesive bonding combined with other joining methods: (a) weldbonding—spot welded and adhesive bonded; (b) riveted (or bolted) and adhesive bonded; and (c) formed plus adhesive bonded.

- For example, the combination of adhesive bonding and spot welding is called ***weldbonding***.
- In addition to the mechanical configuration of the joint, the application must be selected so that the physical and chemical properties of adhesive and adherends are compatible under the service conditions to which the assembly will be subjected.
- Adherend materials include **metals, ceramics, glass, plastics, wood, rubber, leather, cloth, paper, and cardboard.**

- Note that the list includes materials that are rigid and flexible, porous and nonporous, metallic and nonmetallic, and that similar or dissimilar substances can be bonded together.

Adhesive Types

- They can be classified into three categories: (a) natural, (b) inorganic, and (c) synthetic.

(a) Natural Adhesives

- They are derived from natural sources (e.g., plants and animals), including gums, starch, dextrin, soy flour, and collagen.
- This category of adhesive is generally limited to low-stress applications, such as cardboard cartons, furniture, and bookbinding; or where large surface areas are involved (e.g., plywood).

(b) Inorganic Adhesives

- They are based principally on sodium silicate and magnesium oxychloride.
- Although relatively low in cost, they are also low in strength—a serious limitation in a structural adhesive.

(c) Synthetic Adhesives

- They constitute the most important category in manufacturing.
- They include a variety of thermoplastic and thermosetting polymers, many of which are listed and briefly described in **Table below**.
- They are cured by various mechanisms, such as

(1) mixing a catalyst or reactive ingredient with the polymer immediately prior to applying,
(2) heating to initiate the chemical reaction,
(3) radiation curing, such as ultraviolet light, and
(4) curing by evaporation of water from the liquid or paste adhesive.
(5) In addition, some synthetic adhesives are applied as films or as pressure-sensitive coatings on the surface of one of the adherends.

Adhesive	Description and Applications
Anaerobic	Single-component, thermosetting, acrylic-based. Cures by free radical mechanism at room temperature. Applications: sealant, structural assembly.
Modified Acrylics	Two-component thermoset, consisting of acrylic-based resin and initiator/hardener. Cures at room temperature after mixing. Applications: fiberglass in boats, sheet metal in cars and aircraft.
Cyanoacrylate	Single-component, thermosetting, acrylic-based that cures at room temperature on alkaline surfaces. Applications: rubber to plastic, electronic components on circuit boards, plastic and metal cosmetic cases.
Epoxy	Includes a variety of widely used adhesives formulated from epoxy resins, curing agents, and filler/modifiers that harden upon mixing. Some are cured when heated. Applications: aluminum bonding applications and honeycomb panels for aircraft, sheet-metal reinforcements for cars, lamination of wooden beams, seals in electronics.
Hot Melt	Single-component, thermoplastic adhesive hardens from molten state after cooling from elevated temperatures. Formulated from thermoplastic polymers including ethylene vinyl acetate, polyethylene, styrene block copolymer, butyl rubber, polyamide, polyurethane, and polyester. Applications: packaging (e.g., cartons, labels), furniture, footwear, bookbinding, carpeting, and assemblies in appliances and cars.
Pressure-Sensitive Tapes and Films	Usually one component in solid form that possesses high tackiness resulting in bonding when pressure is applied. Formed from various polymers of high-molecular weight. Can be single sided or double-sided. Applications: solar panels, electronic assemblies, plastics to wood and metals.
Silicone	One or two components, thermosetting liquid, based on silicon polymers. Curing by room temperature vulcanization to rubbery solid. Applications: seals in cars (e.g., windshields), electronic seals and insulation, gaskets, bonding of plastics.
Urethane	One or two components, thermosetting, based on urethane polymers. Applications: bonding of fiberglass and plastics.

Adhesive Application Technology

- Industrial applications of adhesive bonding are widespread and growing.
- Major users are **automotive, aircraft, building products, and packaging industries; other industries include footwear, furniture, bookbinding, electrical, and shipbuilding.**
- In this section we consider several issues relating to adhesives application technology.

(a) Surface Preparation

- In order for adhesive bonding to succeed, part surfaces must be extremely clean.
- The strength of the bond depends on the degree of adhesion between adhesive and adherend, and this depends on the cleanliness of the surface.
- For metals, solvent wiping is often used for cleaning, and abrading the surface by sand blasting or other process usually improves adhesion.
- For nonmetallic parts, solvent cleaning is generally used, and the surfaces are sometimes mechanically abraded or chemically etched to increase roughness.
- It is desirable to accomplish the adhesive bonding process as soon as possible after these treatments, since surface oxidation and dirt accumulation increase with time.

(b) Application Methods

- The actual application of the adhesive to one or both part surfaces is accomplished in a number of ways.
- The following list, though incomplete, provides a sampling of the techniques used in industry:

(1) Brushing:
- Performed manually, uses a stiff-bristled brush.
- Coatings are often uneven.

(2) Flowing:
- Using manually operated pressure-fed flow guns, has more consistent control than brushing.

(3) Manual Rollers:
- Similar to paint rollers, are used to apply adhesive from a flat container.

(4) Silk Screening:
- Involves brushing the adhesive through the open areas of the screen onto the part surface, so that only selected areas are coated.

(5) Spraying:

- Uses an air-driven (or airless) spray gun for fast application over large or difficult-to-reach areas.

(6) Automatic Applicators:

- Include various automatic dispensers and nozzles for use on medium- and high-speed production applications.
- Figure (5-55) illustrates the use of a dispenser for assembly.

(7) Roll Coating:

- It is a mechanized technique in which a rotating roller is partially submersed in a pan of liquid adhesive and picks up a coating of the adhesive, which is then transferred to the w.p. surface.
- Figure (5-56) shows one possible application, in which the w.p. is a thin, flexible material (e.g., paper, cloth, leather, plastic).
- Variations of the method are used for coating adhesive onto wood, wood composite, cardboard, and similar materials with large surface areas.

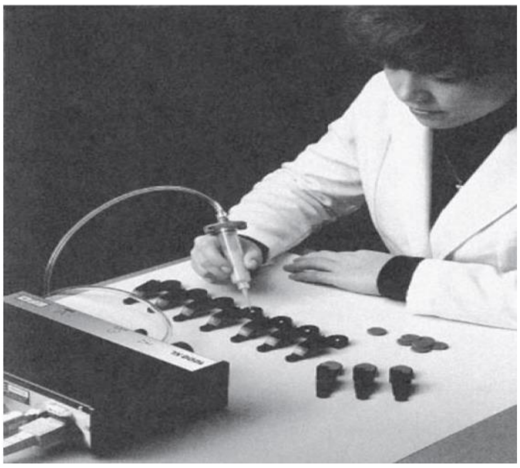

Figure (5-55) Adhesive is dispensed by a manually controlled dispenser to bond parts during assembly.

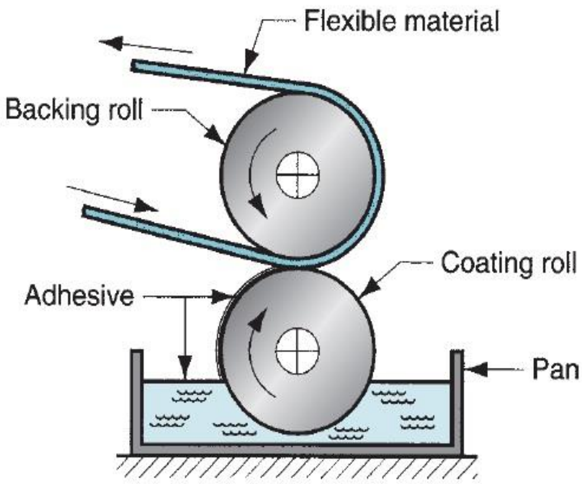

Figure (5-56) Roll coating of adhesive onto thin, flexible material such as paper, cloth, or flexible polymer.

(c) Advantages and Limitations

- Advantages of adhesive bonding are:

(1) the process is applicable to a wide variety of materials;
(2) w.ps. of different sizes and cross sections can be joined—fragile w.ps. can be joined by adhesive bonding;
(3) bonding occurs over the entire surface area of the joint, rather than in discrete spots or along seams as in fusion welding, thereby distributing stresses over the entire area;
(4) some adhesives are flexible after bonding and are thus tolerant of cyclical loading and differences in thermal expansion of adherends;
(5) low temperature curing avoids damage to w.ps. being joined;
(6) sealing as well as bonding can be achieved; and
(7) joint design is often simplified (e.g., two flat surfaces can be joined without providing special part features such as screw holes).

- Principal limitations of this technology include:

(1) joints are generally not as strong as other joining methods;
(2) adhesive must be compatible with materials being joined;
(3) service temperatures are limited;
(4) cleanliness and surface preparation prior to application of adhesive are important;
(5) curing times can impose a limit on production rates; and
(6) inspection of the bonded joint is difficult.