Composite Materials

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Laminar composites

Laminar composites include very thin coatings, thicker protective surfaces, claddings, bimetallic, laminates, and a host of other applications. In addition, the fiber-reinforced composites produced from tapes or fabrics can be considered partly laminar.

Many laminar composites are designed to improve corrosion resistance while retaining low cost, high strength, or light weight. Other important characteristics include superior wear or abrasion resistance, improved appearance, and unusual thermal expansion characteristics.

Rule of Mixtures Some properties of the laminar composite materials parallel to the lamellae are estimated from the rule of mixtures. The density, electrical and thermal

conductivity, and modulus of elasticity parallel to the lamellae can be calculated with little error using following formulas:

$$\text{Density} = \rho_{c,\parallel} = \sum (f_i \rho_i) \tag{17-13}$$

$$\left.\begin{aligned} \text{Electrical conductivity} &= \sigma_{c,\parallel} = \sum (f_i \sigma_i) \\ \text{Thermal conductivity} &= K_{c,\parallel} = \sum (f_i K_i) \\ \text{Modulus of elasticity} &= E_{c,\parallel} = \sum (f_i E_i) \end{aligned}\right\} \tag{17-14}$$

The laminar composites are very anisotropic. The properties perpendicular to the lamellae are:

$$\left.\begin{aligned} \text{Electrical conductivity} &= \frac{1}{\sigma_{c,\perp}} = \sum \left(\frac{f_i}{\sigma_i}\right) \\ \text{Thermal conductivity} &= \frac{1}{K_{c,\perp}} = \sum \left(\frac{f_i}{K_i}\right) \\ \text{Modulus of elasticity} &= \frac{1}{E_{c,\perp}} = \sum \left(\frac{f_i}{E_i}\right) \end{aligned}\right\} \tag{17-15}$$

However, many of the really important properties, such as corrosion and wear resistance, depend primarily on only one of the components of the composite, so the rule of mixtures is not applicable.

Producing Laminar Composites

Several methods are used to produce laminar composites, including a variety of deformation and joining techniques used primarily for metals. (Figure 17-30).

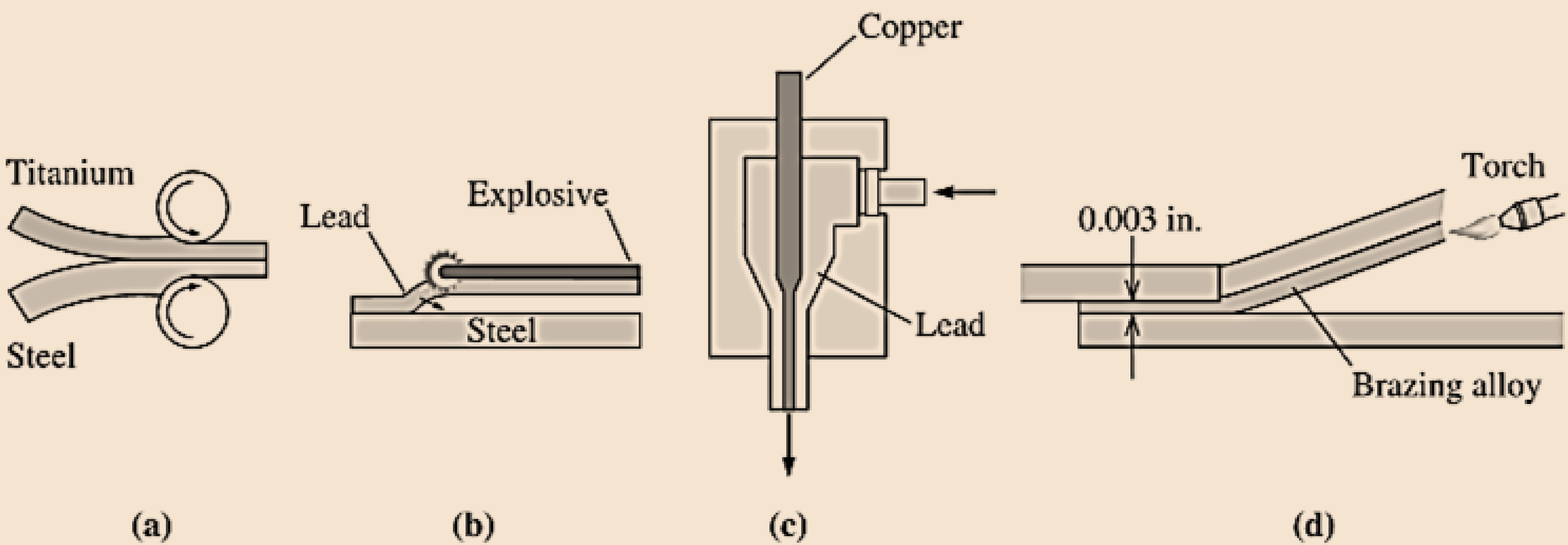

Figure 17-30 Techniques for producing laminar composites: (a) roll bonding, (b) explosive bonding, (c) coextrusion, and (d) brazing.

Individual plies are often joined by adhesive bonding, as is the case in producing plywood. Polymer-matrix composites built up from several layers of fabric or tape prepregs are also joined by adhesive bonding; a film of unpolymerized material is placed between each layer of prepreg. When the layers are pressed at an elevated temperature, polymerization is completed and the prepregged fibers are joined to produce composites that may be dozens of layers thick.

Most of the metallic laminar composites, such as claddings and bimetallics, are produced by deformation bonding, such as **hot- or cold-roll bonding**. The pressure exerted by the rolls breaks up the oxide film at the surface, brings the surfaces intoatom-to-atom contact, and permits the two surfaces to be joined

Explosive bonding can also be used. An explosive charge provides the pressure required to join metals. This process is particularly well suited for joining very large plates that will not fit into a rolling mill

Very simple laminar composites, such as coaxial cable, are produced by coextruding two materials through a die in such a way that the soft material surrounds the harder material. Metal conductor wire can be coated with an insulating thermoplastic polymer in this manner.

Brazing can join composite plates. The metallic sheets are separated by a very small clearance—preferably, about 0.003 in.—and heated above the melting temperature of the brazing alloy. The molten brazing alloy is drawn into the thin joint by capillary action.

8-2Exampl and application of laminar composites

The number of laminar composites is so varied and their applications and intentions are so numerous that we cannot make generalizations concerning their behavior. Instead we will examine the characteristics of a few commonly used examples.

Laminates Laminates are layers of materials joined by an organic adhesive. In laminated safety glass, a plastic adhesive, such as polyvinyl butyral (PVB), joins two pieces of glass; the adhesive prevents fragments of glass from flying about when the glass is broken .Laminates are used for insulation in motors, for gears, for printed circuit boards, and for decorative items such as Formica1 countertops and furniture. Microlaminates include composites composed of alternating layers of aluminum sheet and fiber-reinforced polymer. Arall (aramid-aluminum laminate) and Glare (glassaluminum laminate) have been developed as possible skin materials for aircraft. In Arall, an aramid fiber such as KevlarTM is prepared as a fabric or unidirectional tape, impregnated with an adhesive, and laminated between layers of aluminum alloy (Figure 17-31). The composite laminate has an unusual combination of strength, sti¤ness, corrosion resistance, and light weight. Fatigue resistance is improved, since the interface between the layers may block cracks. Compared with polymer-matrix composites, the microlaminates have good resistance to lightning-strike damage (which is important in aerospace applications), are formable and machinable, and are easily repaired.

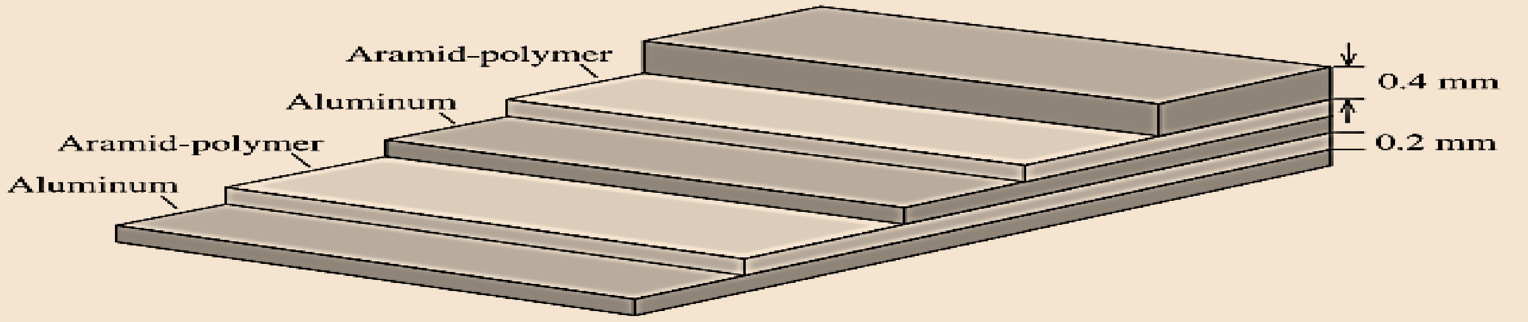

Figure 17-31 Schematic diagram of an aramid-aluminum laminate, Arall, which has potential for aerospace applications.

Clad Metals Clad materials are metal-metal composites. A common example of cladding is United States silver coinage. A Cu-80% Ni alloy is bonded to both sides of a Cu-20% Ni alloy. The ratio of thicknesses is about 1/6:2/3:1/6. The high-nickel alloy is a silver color, while the predominantly copper core provides low cost. Clad materials provide a combination of good corrosion resistance with high strength. Alclad is a clad composite in which commercially pure aluminum is bonded to higher-strength aluminum alloys. The pure aluminum protects the higher-strength alloy from corrosion. The thickness of the pure aluminum layer is about 1% to 15% of the total thickness. Alclad is used in aircraft construction, heat exchangers, building construction, and storage tanks, where combinations of corrosion resistance, strength, and light weight are desired.

Bimetallics Temperature indicators and controllers take advantage of the different coefficients of thermal expansion of the two metals in laminar composite. If two pieces of metal are heated, the metal with the higher coefficient of thermal expansion becomes longer. If the two pieces of metal are rigidly bonded together, the difference in their coefficients causes the strip to bend and produce a curved surface. The amount of movement depends on the temperature. By measuring the curvature or deflection of the strip, we can determine the temperature. Likewise, if the free end of the strip activates a relay, the strip can turn on or off a furnace or air conditioner to regulate temperature

Conditions of selection bimetallics

Metals selected for bimetallics must have

(a) very different coefficients of thermal expansion,

(b) expansion characteristics that are reversible and repeatable, and

(c) a high modulus of elasticity, so that the bimetallic device can do work.

Often the low expansion strip is made from Invar, an iron-nickel alloy, whereas the high-expansion strip may be brass, Monel, or pure nickel.

Bimetallics can act as circuit breakers as well as thermostats; if a current passing through the strip becomes too high, heating causes the bimetallic to deflect and break the circuit.

Multilayer capacitors Similar geometry is used to make billions of multi-layer capacitors. Their structure is comprisesd of thin sheets of BaTiO3-based ceramics separated by Ag/Pd or Ni electrodes

8-3Sandwich structure

Sandwich materials have thin layers of a facing material joined to a lightweight filler material, such as a polymer foam. Neither the filler nor the facing material is strong or rigid, but the composite possesses both properties. A familiar example is corrugated cardboard. A corrugated core of paper is bonded on either side to flat, thick paper. Neither the corrugated core nor the facing paper is rigid, but the combination is.

Honeycomb structure

Another important example is the honeycomb structure used in aircraft applications. A honeycomb is produced by gluing thin aluminum strips at selected locations. The honeycomb material is then expanded to produce a very low-density cellular panel that, by itself, is unstable (Figure 17-32)

When an aluminum facing sheet is adhesively bonded to either side of the honeycomb, however, a very stiff, rigid, strong, and exceptionally lightweight sandwich with a density as low as 0.04 g/cm3 is obtained. The honeycomb cells can have a variety of shapes, including hexagonal, square, rectangular, and sinusoidal, and they can be made from aluminum, fiberglass, paper,

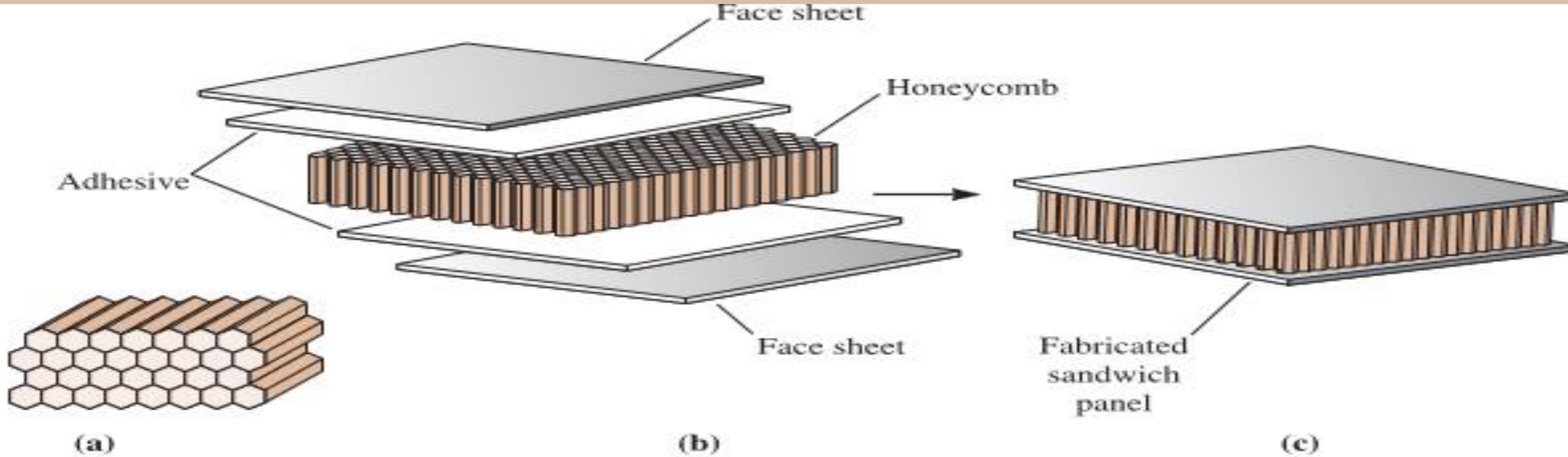

Figure 17-32 (a) A hexagonal cell honeycomb core, (b) can be joined to two face sheets by means of adhesive sheets, (c) producing an exceptionally lightweight yet stiff, strong honeycomb sandwich structure.

aramid polymers, and other materials. The honeycomb cells can be filled with foam or fiberglass to provide excellent sound and vibration absorption. Figure 17-33 describes one method by which the honeycomb can be fabricated.

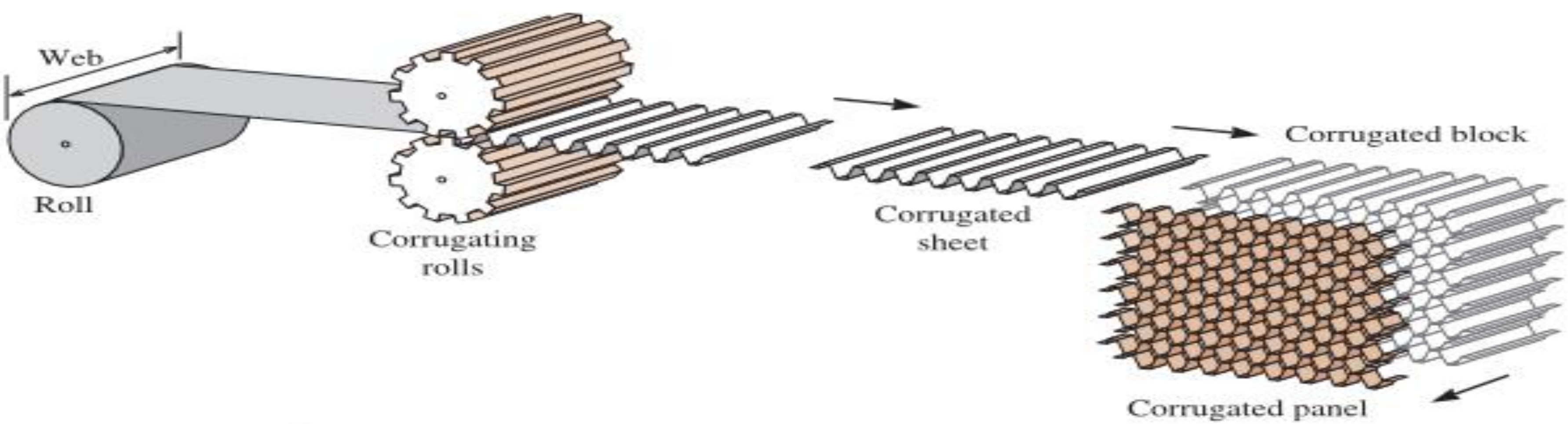

Figure 17-33 In the corrugation method for producing a honeycomb core, the material (such as aluminum) is corrugated between two rolls. The corrugated sheets are joined together with

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