31.5 Resistance Welding

The category of *resistance welding* (RW) covers a number of processes in which the heat required for welding is produced by means of *electrical resistance* across the two components to be joined. These processes have major advantages, such as high-quality welds that do not require consumable electrodes, shielding gases, or flux, and can be produced quickly. Resistance welding lends itself very well to automation, and is often applied using welding robots (see Section 37.6).

The heat generated in resistance welding is given by the general expression

$$H = I^2 Rt, \tag{31.1}$$

where

H = Heat generated in joules (watt-seconds)
I = Current (in amperes)
R = Resistance (in ohms)
t = Time of current flow (in seconds)

Equation (31.1) is often modified, so that it represents the actual heat energy available in the weld, by including a factor K, which compensates for the energy losses through conduction and radiation. The equation then becomes

$$H = I^2 RtK, \tag{31.2}$$

where it can be noted that the value of K is less than unity.

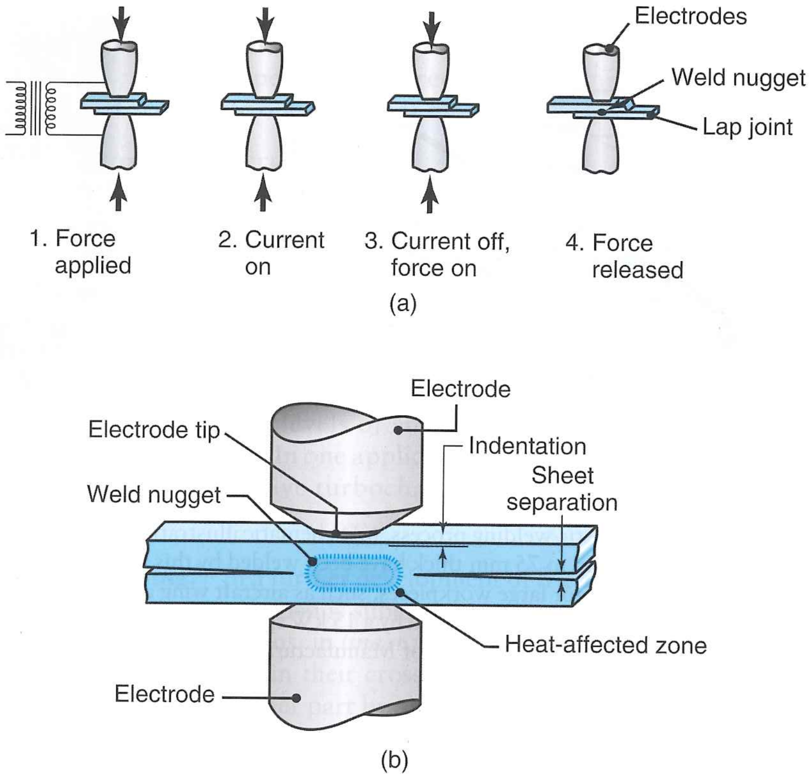

FIGURE 31.6 (a) Sequence of events in resistance spot welding of a lap joint. (b) Cross-section of a spot weld, showing the weld nugget and the indentation of the electrode on the sheet surfaces. This is one of the most commonly used processes in sheet-metal fabrication and in automotive-body assembly.

The *total resistance* is the sum of the following (see Fig. 31.6):

1. Resistances of the electrodes
2. Electrode–workpiece contact resistance
3. Resistances of the individual parts to be welded
4. Contact resistance between the two workpieces to be joined (faying surfaces)

The actual temperature rise in the joint depends on the specific heat and the thermal conductivity of the metals to be joined. For example, metals such as aluminum and copper have high thermal conductivity (see Table 3.1), thus they require high heat concentrations. Similar as well as dissimilar metals can be joined by resistance welding. The magnitude of the current in resistance-welding operations may be as high as 100,000 A, but the voltage is typically only 0.5 to 10 V. The strength of the bond depends on surface roughness and on the cleanliness of the mating surfaces. Oil films, paint, and thick oxide layers should therefore be removed prior to welding, although the presence of uniform, *thin* layers of oxide and other contaminants is not as critical.

Developed in the early 1900s, resistance-welding processes require specialized machinery, much of which is now operated by programmable computer control. Generally, the machinery is not portable, and the process is suitable primarily for use in manufacturing plants and machine shops. The operator skill required is minimal, particularly with modern machinery.

31.5.1 Resistance Spot Welding

In *resistance spot welding* (RSW), the tips of two opposing solid, cylindrical electrodes touch a lap joint of two sheet metals, and resistance heating produces a spot weld (Fig. 31.6a). In order to obtain a strong bond in the **weld nugget**, pressure is applied until the current is turned off and the weld has solidified. Accurate control and timing of the alternating current (AC) and of the pressure are essential in resistance welding. In the automotive industry, for example, the number of cycles ranges up to about 30 at a frequency of 60 Hz. (See also *high-frequency resistance welding* in Section 31.5.3)

The surfaces of a spot weld have a slightly discolored indentations. The weld nugget (Fig. 31.6b) may be up to 10 mm in diameter. Currents range from 3000 to 40,000 A, the current level depending on the materials being welded and their thicknesses; for example, the current is typically 10,000 A for steels and 13,000 A for aluminum. Electrodes generally are made of copper alloys and must have sufficient electrical conductivity and hot strength to maintain their shape.

The simplest and most commonly used resistance-welding process, spot welding, may be performed by means of single (most common) or multiple pairs of electrodes (as many as a hundred or more); the required pressure is supplied through mechanical or pneumatic means. **Rocker-arm-type** spot-welding machines normally are used for smaller parts; **press-type** machines are used for larger workpieces. The shape and surface condition of the electrode tip and the accessibility of the site are important factors in spot welding. A variety of electrode shapes are used for areas that are difficult to reach (Fig. 31.7).

Spot welding is widely used for fabricating sheet-metal parts; examples range from attaching handles to stainless-steel cookware (Fig. 31.8a) to spot-welding mufflers (Fig. 31.8b) and large sheet-metal structures. Modern spot-welding

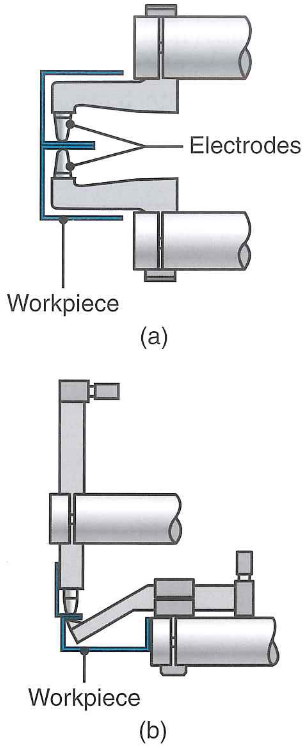

FIGURE 31.7 Two electrode designs for easy access to the components to be welded.

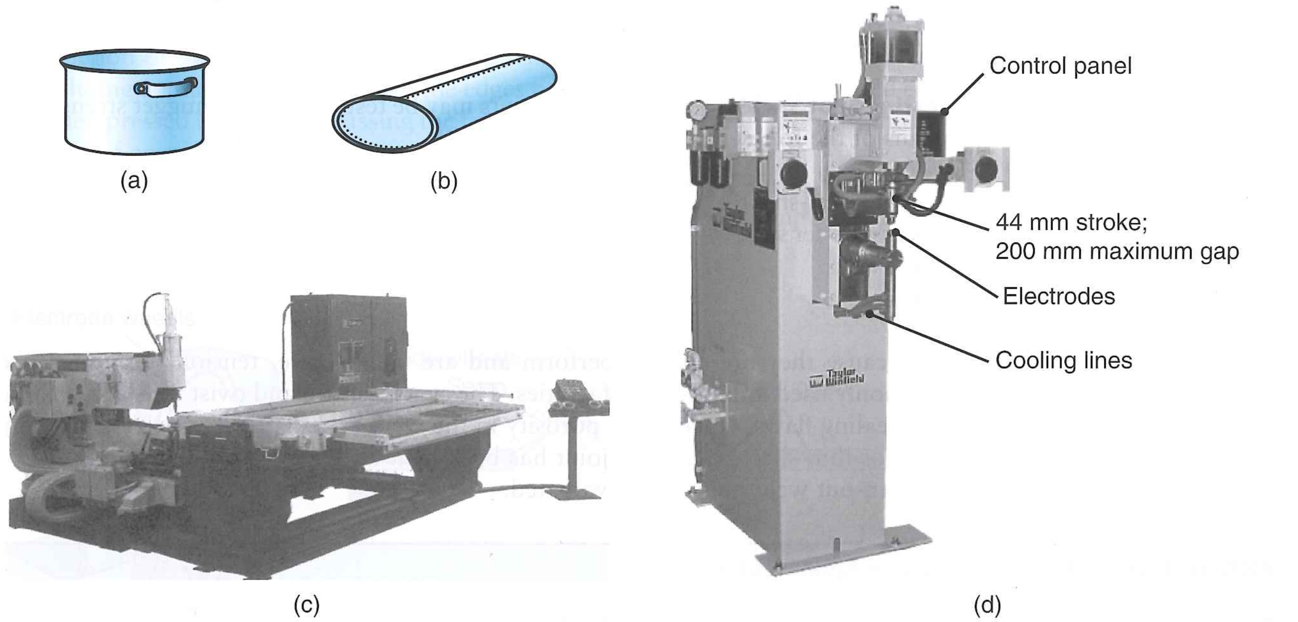

FIGURE 31.8 Spot-welded (a) cookware and (b) muffler. (c) A large automated spot-welding machine. The welding tip can move in three principal directions; sheets as large as 2.2 m × 0.55 m can be accommodated in this machine, with proper workpiece supports. (d) A spot welding machine. *Source:* (c) and (d) Courtesy of Taylor-Winfield Technologies, Inc.

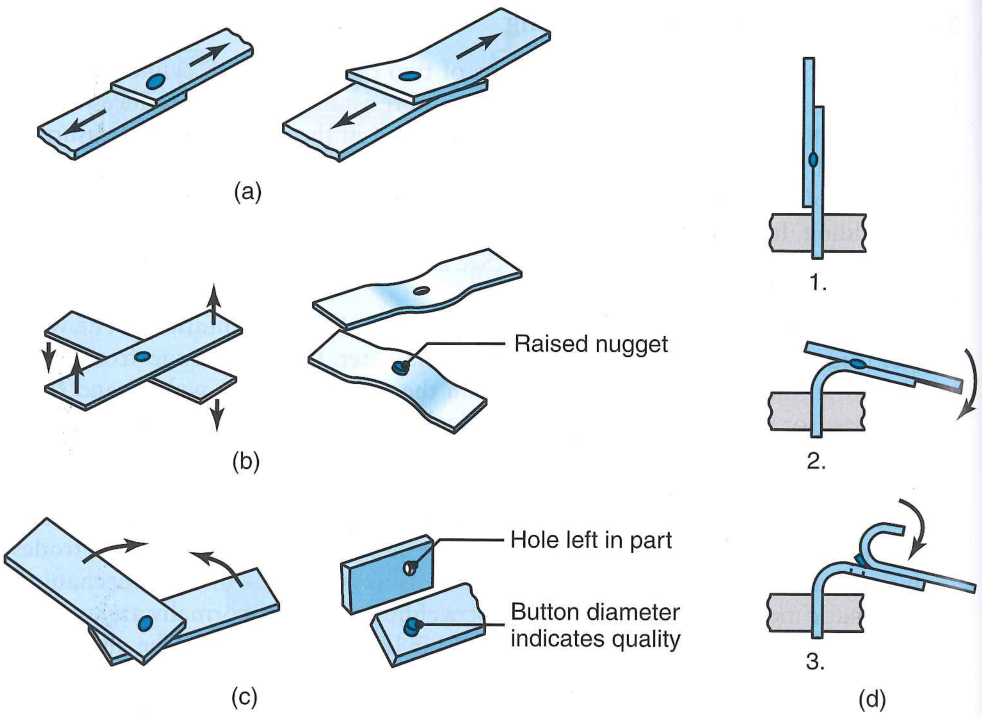

FIGURE 31.9 Test methods for spot welds: (a) tension-shear test, (b) cross-tension test, (c) twist test, and (d) peel test (see also Fig. 32.9).

equipment is computer controlled, for optimum timing of current and pressure, and the spot-welding guns are manipulated by programmable robots. Automobile bodies can have as many as 10,000 spot welds; they are welded at high rates using multiple electrodes (see Fig. I.9 in the General Introduction).

Testing Spot Welds. Spot-welded joints may be tested for weld-nugget strength by means of the following techniques (Fig. 31.9):

- Tension-shear
- Cross-tension
- Twist
- Peel

Because they are easy to perform and are inexpensive, tension-shear tests are commonly used in fabricating facilities. The cross-tension and twist tests are capable of revealing flaws, cracks, and porosity in the weld area. The peel test is commonly used for thin sheets; after the joint has been bent and peeled, the shape and size of the torn-out weld nugget are evaluated.

EXAMPLE 31.2 Heat Generated in Spot Welding

Given: Assume that two 1-mm thick steel sheets are being spot-welded at a current of 5000 A and over a current flow time of 0.1 s by means of electrodes 5 mm in diameter.

Find: Estimate the heat generated and its distribution in the weld zone if the effective resistance in the operation is 200 $\mu\Omega$.

Solution: According to Eq. (31.1),

$$\text{Heat} = (5000)^2(0.0002)(0.1) = 500 \text{ J}.$$

From the information given, the weld-nugget volume can be estimated to be 30 mm^3. Assume that the density for steel (Table 3.1) is 8000 kg/m^3; then the weld nugget has a mass of 0.24 g. The heat required to melt 1g of teel is about 1400 J, so the heat required to melt the weld nugget is $(1400)(1400)(0.24) = 336$ J. The remaining heat (164 J) is dissipated into the metal surrounding the nugget.

31.5.2 Resistance Seam Welding

Resistance seam welding (RSEW) is a modification of spot welding wherein the electrodes are replaced by rotating wheels or rollers (Fig. 31.10a). Using a continuous AC power supply, the electrically conducting rollers produce a spot weld whenever the current reaches a sufficiently high level in the AC cycle. The typical welding speed is 1.5 m/min for thin sheets.

With a sufficiently high frequency or slow traverse speed, these spot welds actually overlap into a continuous seam and produce a joint that is liquid- and gas-tight (Fig. 31.10b). The RSEW process is used to make the longitudinal seam of steel cans (for household products), mufflers, and gasoline tanks.

In **roll spot welding**, the current to the rolls is applied only intermittently, resulting in a series of spot welds that are at specified intervals along the length of the seam (Fig. 31.10c). In **mash seam welding** (Fig. 31.10d), the overlapping welds are about one to two times the sheet thickness, and the welded seam thickness is only about 90% of the original sheet thickness. This process is also used in producing *tailor-welded sheet-metal blanks*, which can be made by laser welding as well (see Section 16.2.2).

31.5.3 High-frequency Resistance Welding

High-frequency resistance welding (HFRW) is similar to seam welding, except that a high-frequency current of up to 450 kHz is employed. A typical application is the production of *butt-welded* tubing or pipe, where the current is conducted through two sliding contacts (Fig. 31.11a) to the edges of roll-formed tubes. The heated edges are then pressed together by passing the tube through a pair of squeeze rolls; the flash formed, if any, is then trimmed off.

Structural sections, such as I-beams, can be fabricated by HFRW, by welding the webs and flanges made from long, flat pieces. Spiral pipe and tubing, finned tubes

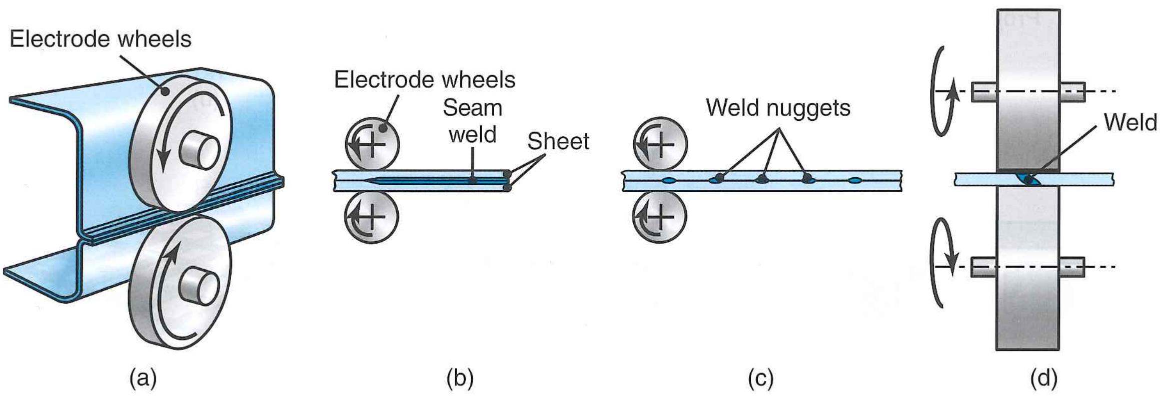

FIGURE 31.10 (a) Seam-welding process in which rotating rolls act as electrodes; (b) overlapping spots in a seam weld; (c) roll spot welds; and (d) mash seam welding.

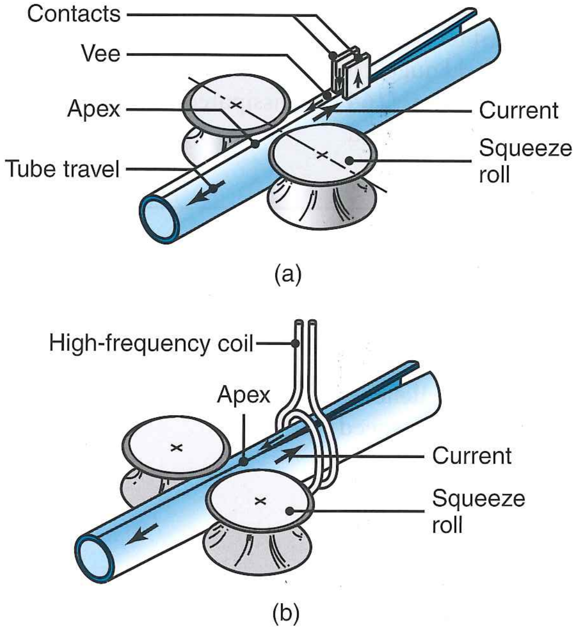

FIGURE 31.11 Two methods of high-frequency continuous butt welding of tubes.

for heat exchangers, and wheel rims also may be made by this technique. In another method, called **high-frequency induction welding** (HFIW), the roll-formed tube is subjected to high-frequency induction heating, as shown in Fig. 31.11b.

31.5.4 Resistance Projection Welding

In *resistance projection welding* (RPW), high electrical resistance at the joint is developed by embossing one or more projections (*dimples*; see Fig. 16.39) on one of the surfaces to be welded (Fig. 31.12). The projections may be round or oval for design or strength purposes. High localized temperatures are generated at the projections, which are in contact with the flat mating part. Typically made of copper-based alloys, the electrodes are large and flat, and are water cooled to keep their temperature low. Weld nuggets are similar to those in spot welding, and are formed as the electrodes exert pressure to soften and compress and flatten the projections.

Spot-welding equipment can be used for resistance projection welding by modifying the electrodes. Although the embossing of the workpieces adds to production cost, the operation produces several welds in one pass and extends electrode life; moreover, it is capable of welding metals of different thicknesses, such as a sheet welded over a plate. Nuts and bolts also can be welded to sheets and plates by this process (Figs. 31.12c and d), with projections that may be produced either by machining or forging. Joining a network of rods and wires (such as the ones making up metal baskets, grills (Fig. 31.12e), oven racks, and shopping carts) is considered resistance projection welding, because of the many small contact areas between crossing wires (grids).

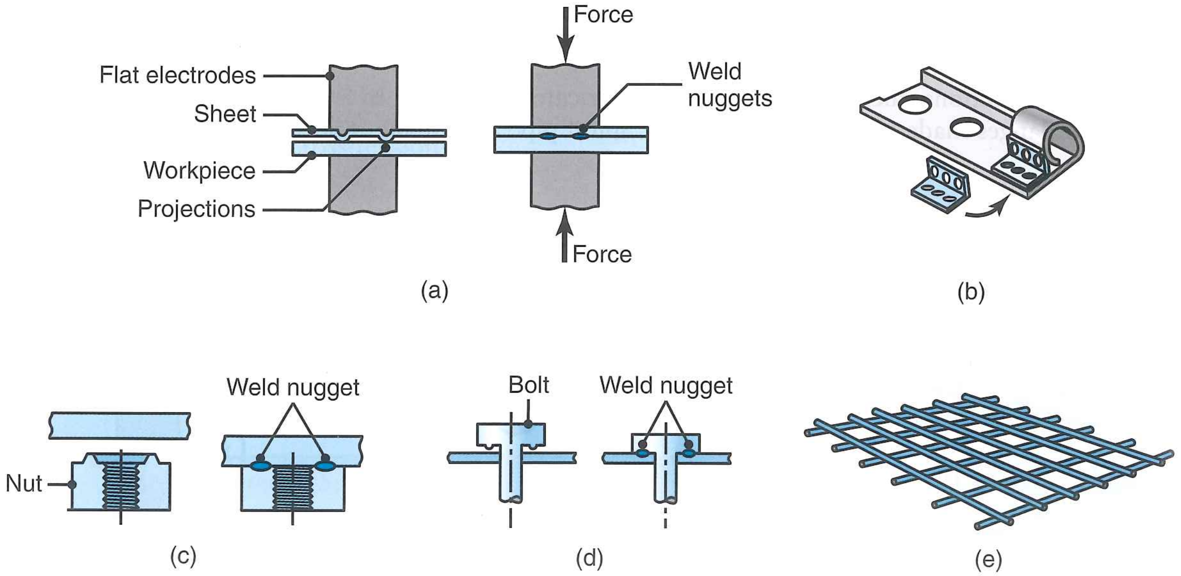

FIGURE 31.12 (a) Schematic illustration of resistance projection welding. (b) A welded bracket. (c) and (d) Projection welding of nuts or threaded bosses and studs. (e) Resistance-projection-welded grills.

31.5.5 Flash Welding

In *flash welding* (FW), also called **flash butt welding**, heat is generated very rapidly from the arc as the ends of the two members begin to make contact and develop an electrical arc at the joint (Fig. 31.13a). After the proper temperature is reached and the interface begins to soften, an axial force is applied at a controlled rate, producing a weld by plastic deformation of the joint. The mechanism involved is called *hot upsetting*, and the term *upset welding* (UW) also is used for this process. Some molten metal is expelled from the joint as a shower of sparks during the process, hence the name *flash welding*. Because of the presence of an arc, the process can also be classified as arc welding.

Impurities and contaminants are squeezed out during this operation, and a significant amount of material may be burned off during the welding process. The joint quality is good, and it may be machined later to further improve its appearance. The machines for flash welding usually are automated and large, and have a variety of power supplies ranging from 10 to 1500 kVA.

The FW process is suitable for end-to-end or edge-to-edge joining of strips and sheets of similar or dissimilar metals 0.2 to 25 mm thick, and for endjoining bars 1 to 75 mm in diameter. Thinner sections have a tendency to buckle under the axial force applied during welding. Rings made by forming (such as by the methods shown in Fig. 16.22) can be flash butt welded. In addition, the process is also used to repair broken band-saw blades (Section 24.5) using fixtures that are mounted on the band-saw frame.

The flash-welding process can be automated for reproducible welding operations. Typical applications are the joining of pipe and of tubular shapes for metal furniture, doors, and windows. The process also is used for welding the ends of sheets or coils of wire, in continuously operating rolling mills (Chapter 13) and in the feeding of

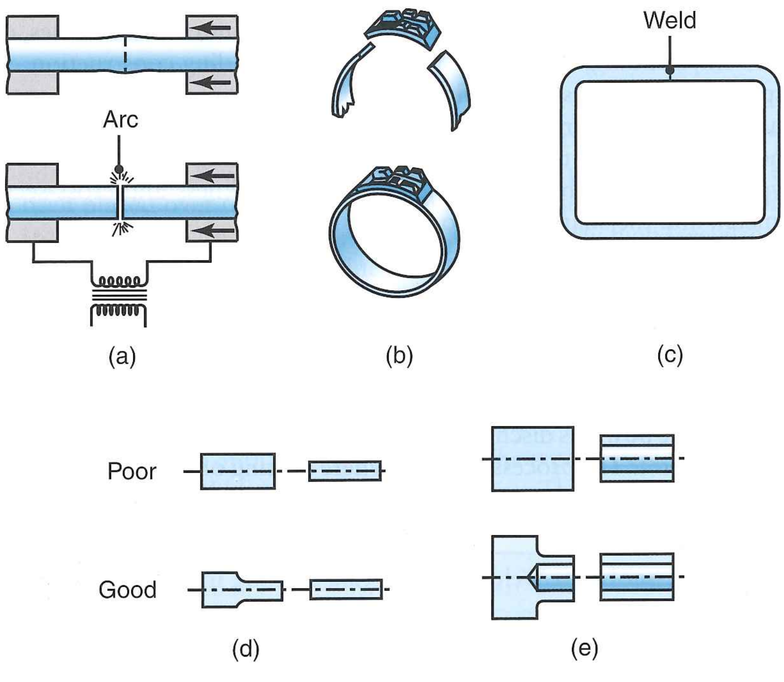

FIGURE 31.13 (a) Flash-welding process for end-to-end welding of solid rods or tubular parts. (b) and (c) Typical parts made by flash welding. (d) and (e) Some design guidelines for flash welding.

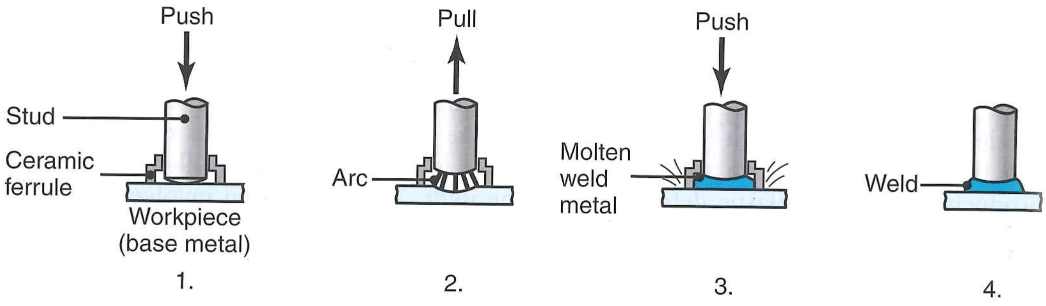

FIGURE 31.14 Sequence of operations in stud welding, commonly used for welding bars, threaded rods, and various fasteners onto metal plates.

wire-drawing equipment (Section 15.11). Some design guidelines for mating surfaces in flash welding are shown in Figs. 31.13d and e; note the importance of having uniform cross-sections at the joint.

31.5.6 Stud Welding

Stud welding (SW), also called *stud arc welding*, is similar to flash welding. The stud, which may be a threaded metal rod, hanger, or handle, serves as one of the electrodes while it is being joined to another component, usually a flat plate (Fig. 31.14). Polarity for aluminum is typically direct-current electrode positive (DCEP); for steel, it is direct-current electrode negative (DCEN).

In order to concentrate the heat generated, prevent oxidation, and retain the molten metal in the weld zone, a disposable ceramic ring (called *ferrule*) is placed around the joint. The equipment for stud welding can be automated, with various controls for arcing and for applying pressure. Portable stud-welding equipment also is available. Typical applications of stud welding include automobile bodies, electrical panels, and shipbuilding; the process is also used in building construction.

In **capacitor-discharge stud welding**, a DC arc is produced from a capacitor bank. No ferrule or flux is required, because the welding time is on the order of only 1 to 6 ms. The choice between this process and stud arc welding depends on such factors as the types of metals to be joined, the workpiece thickness and cross-section, the stud diameter, and the shape of the joint.

31.5.7 Percussion Welding

The resistance-welding processes already described usually employ an electrical transformer, to meet the power requirements; alternatively, the electrical energy for welding may be stored in a capacitor. *Percussion welding* (PEW) utilizes this technique, in which the power is discharged within 1 to 10 ms in order to develop localized high heat at the joint. The process is useful where heating of the components adjacent to the joint is to be avoided, as in electronic assemblies and electrical wires.

EXAMPLE 31.3 Resistance Welding versus Laser-beam Welding in the Can-making Industry

The cylindrical bodies of cans for food and for household products have been resistance seam welded (with a lap joint up the side of the can) for many years. Beginning in about 1987, laser-beam welding technology was introduced into the can-making industry. The joints are welded by lasers, with the same productivity as in resistance welding but with the following advantages:

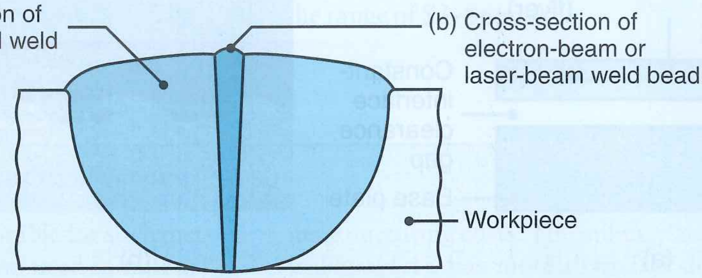

FIGURE 31.15 The relative sizes of the weld beads obtained by tungsten-arc and by electron-beam or laser-beam welding.

- As opposed to the lap joints suitable for resistance welding, laser welding utilizes butt joints; thus, some material is saved. Multiplied by the billions of cans made each year, this amount becomes a very significant savings.
- Because laser welds have a very narrow zone (Fig. 31.15; see also Fig. 30.15), the unprinted area on the can surface (called the printing margin) is greatly reduced. As a result, the can's appearance and its customer acceptance are improved.
- The resistance lap-welded joint can be subject to corrosion by the contents of the can (which can be acidic, such as tomato juice). This effect may change the taste and can cause a potential liability risk. A butt joint made by laser-beam welding eliminates this problem.

Source: Courtesy of G.F. Benedict.