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.

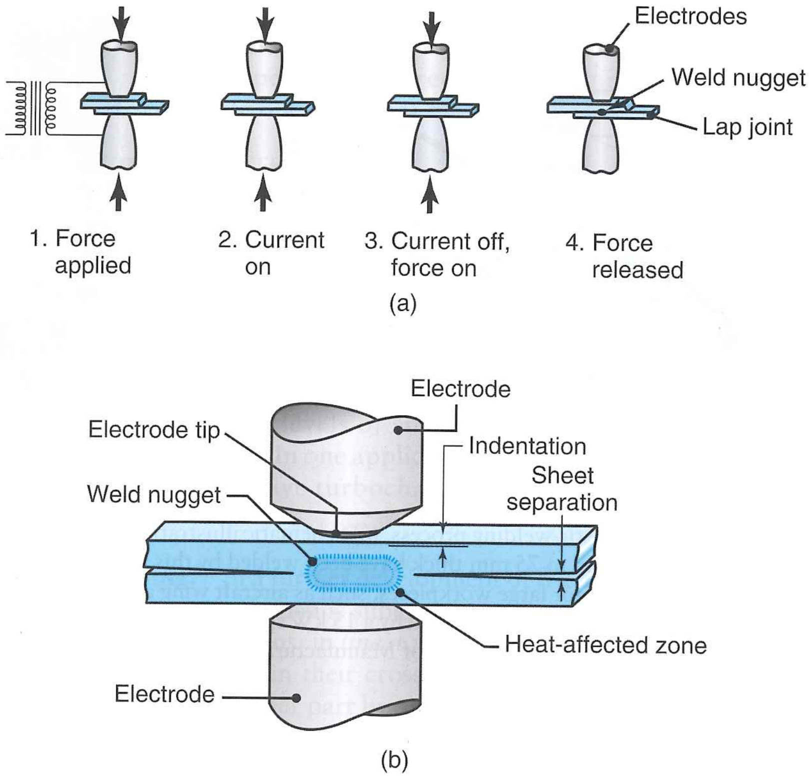

FIGURE 31.6 (a) Sequence of events in resistance spot welding of a lap joint. (b) Cross-section of a spot weld, showing the weld nugget and the indentation of the electrode on the sheet surfaces. This is one of the most commonly used processes in sheet-metal fabrication and in automotive-body assembly.

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

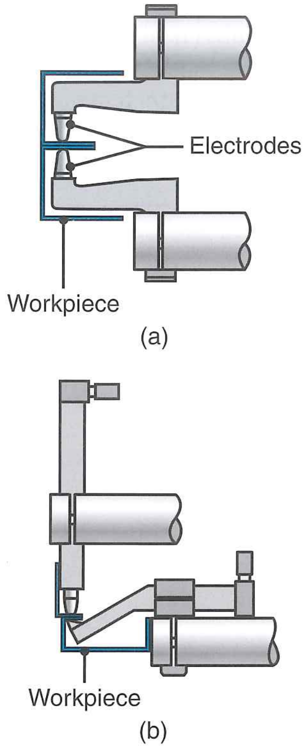

FIGURE 31.7 Two electrode designs for easy access to the components to be welded.

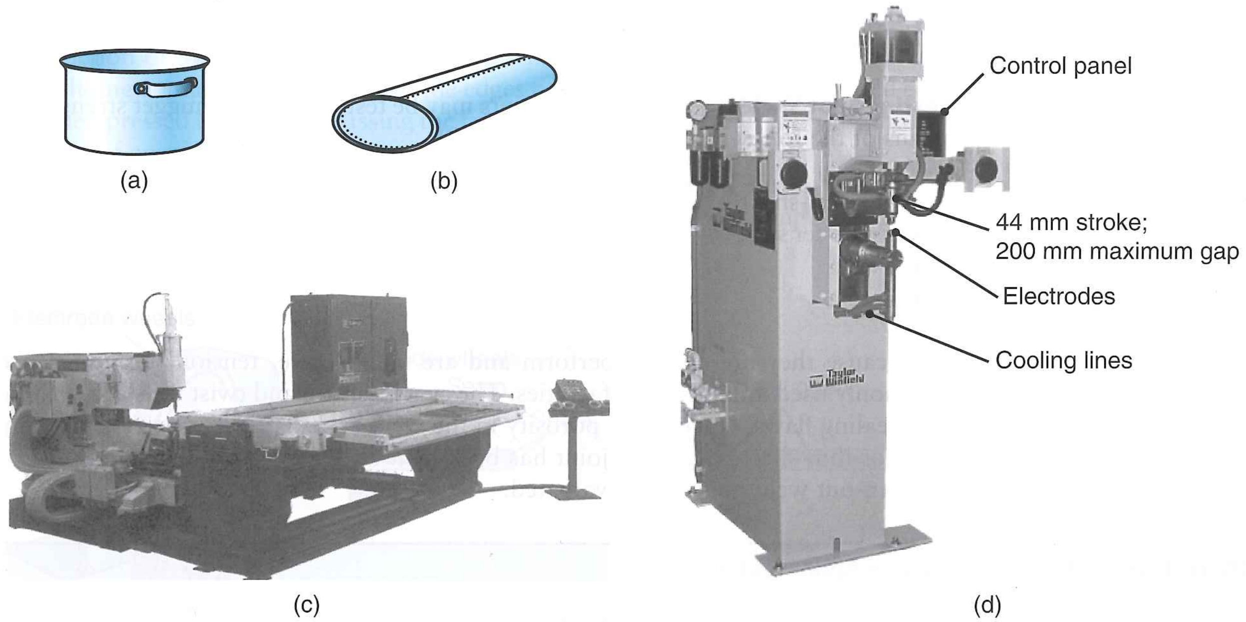

FIGURE 31.8 Spot-welded (a) cookware and (b) muffler. (c) A large automated spot-welding machine. The welding tip can move in three principal directions; sheets as large as 2.2 m × 0.55 m can be accommodated in this machine, with proper workpiece supports. (d) A spot welding machine. *Source:* (c) and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

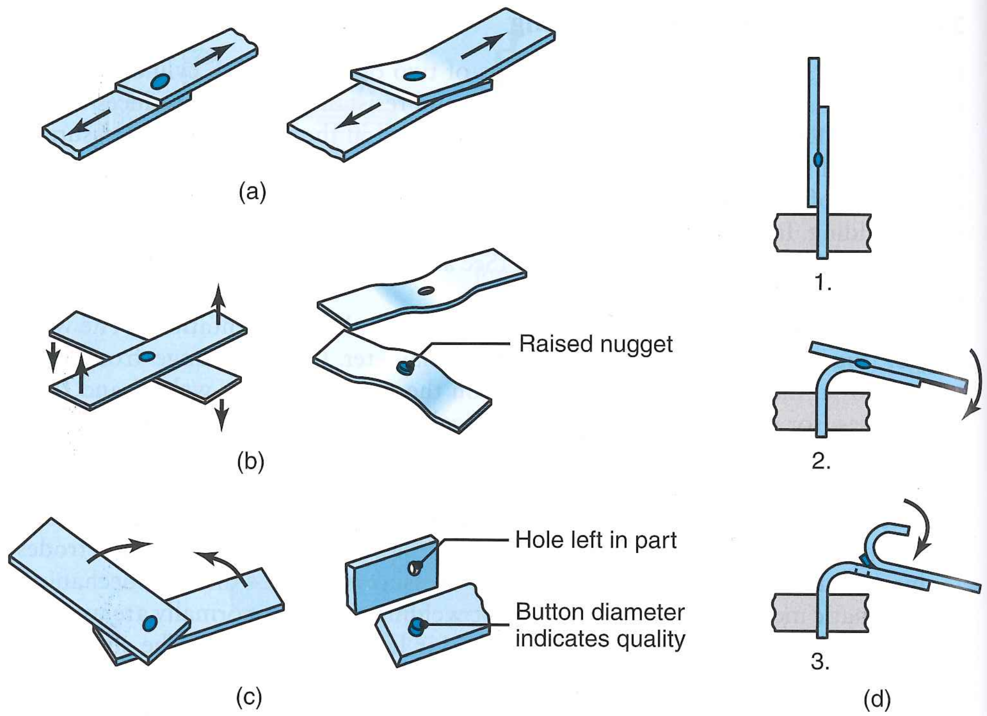

FIGURE 31.9 Test methods for spot welds: (a) tension-shear test, (b) cross-tension test, (c) twist test, and (d) peel test (see also Fig. 32.9).

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.