

2. RESISTANCE WELDING

Resistance Welding (RW) is a group of fusion-welding processes that uses a combination of heat and pressure to accomplish coalescence, the heat being generated by electrical resistance to current flow at the junction to be welded. The principal components in resistance welding are shown in Figure 7 for a resistance spot-welding operation, the most widely used process in the group. The components include work parts to be welded (usually sheet metal parts), two opposing electrodes, a means of applying pressure to squeeze the parts between the electrodes, and an AC power supply from which a controlled current can be applied.

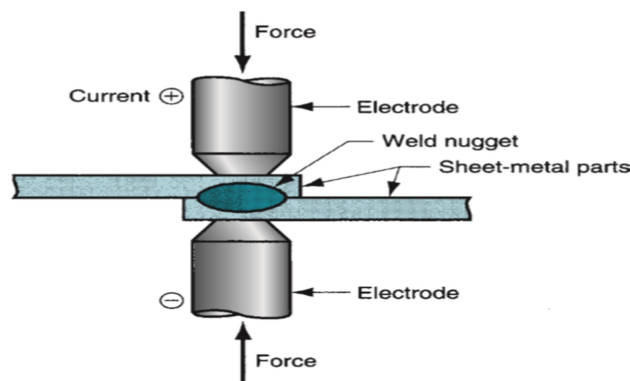


FIGURE 7. Resistance welding (RW), the components in spot welding.

The operation results in a fused zone between the two parts, called a weld nugget in spot welding. By comparison to arc welding, resistance welding uses no shielding gases, flux, or filler metal; and the electrodes that conduct electrical power to the process are non-consumable. RW is classified as fusion welding because the applied heat almost always causes melting of the faying surfaces. However, there are exceptions. Some welding operations based on resistance heating use temperatures below the melting points of the base metals, so fusion does not occur.

2.1. Power Source in Resistance Welding

The heat energy supplied to the welding operation depends on current flow, resistance of the circuit, and length of time the current is applied. This can be expressed by the equation $H = I^2 R t$

where H = heat generated, J (to convert to Btu divide by 1055); I = current, A; R = electrical resistance, Ω ; and t = time, s.

The current used in resistance welding operations is very high (5000 to 20,000 A, typically), although voltage is relatively low (usually below 10 V). The duration of the current is short in most processes, perhaps lasting 0.1 to 0.4 s in a typical spot-welding operation. The reason why such a high current is used in RW is because (1) the squared term in Eq. (above) amplifies the effect of current, and (2) the resistance is very low (around 0.0001 V).

Resistance in the welding circuit is the sum of:

- (1) resistance of the electrodes,
- (2) resistances of the work parts,
- (3) contact resistances between electrodes and work parts, and
- (4) contact resistance of the faying surfaces.

Thus, heat is generated in all of these regions of electrical resistance. The ideal situation is for the faying surfaces to be the largest resistance in the sum, since this is the desired location of the weld. The resistance of the electrodes is minimized by using metals with very low resistivities, such as copper. Also, the electrodes are often water cooled to dissipate **تبدد** the heat that is generated there. The work part resistances are a function of the resistivities of the base metals and the part thicknesses. The contact resistances between the electrodes and the parts are determined by the contact areas (i.e., size and shape of the electrode) and the condition of the surfaces (e.g., cleanliness of the work surfaces and scale on the electrode). Finally, the resistance at the faying surfaces depends on surface finish, cleanliness, contact area, and pressure. No paint, oil, dirt, or other contaminants should be present to separate the contacting surfaces.

Success in resistance welding depends on pressure as well as heat.

The principal functions of pressure in RW are to:

- (1) force contact between the electrodes and the work parts and between the two work surfaces prior to applying current, and
- (2) press the faying surfaces together to accomplish coalescence when the proper welding temperature has been reached.

General advantages of resistance welding include

- (1) no filler metal is required,
- (2) high production rates are possible,
- (3) lends itself to mechanization and automation,
- (4) operator skill level is lower than that required for arc welding, and
- (5) good repeatability and reliability.

Drawbacks are

- (1) equipment cost is high-usually much higher than arc-welding operations, and
- (2) types of joints that can be welded are limited to lap joints for most RW processes.

2.2. Resistance-Welding Processes

The resistance-welding processes of most commercial importance are spot, seam, and projection welding.

Resistance Spot Welding (RSW), it is widely used in mass production of automobiles, appliances, metal furniture, and other products made of sheet metal. If one considers that a typical car body has approximately 10,000 individual spot welds, and that the annual production of automobiles throughout the world is measured in tens of millions of units, the economic importance of resistance spot welding can be appreciated. Resistance spot welding (RSW) is an RW process in which fusion of the faying surfaces of a lap joint is achieved at one location by opposing electrodes. The process is used to join sheet-metal parts of thickness 3 mm or less, using a series of spot welds, in situations where an airtight assembly is not required. The size and shape of the weld spot is determined by the electrode tip, the most common electrode shape being round, but hexagonal, square, and other shapes are also used. The resulting weld nugget is typically 5 to 10 mm in diameter, with a heat-affected zone extending slightly beyond the nugget into the base metals. If the weld is made properly, its strength will be comparable to that of the surrounding metal. The steps in a spot welding cycle are depicted in Figure 8.

Materials used for RSW electrodes consist of two main groups: (1) copper-based alloys and (2) refractory metal compositions such as copper and tungsten combinations.

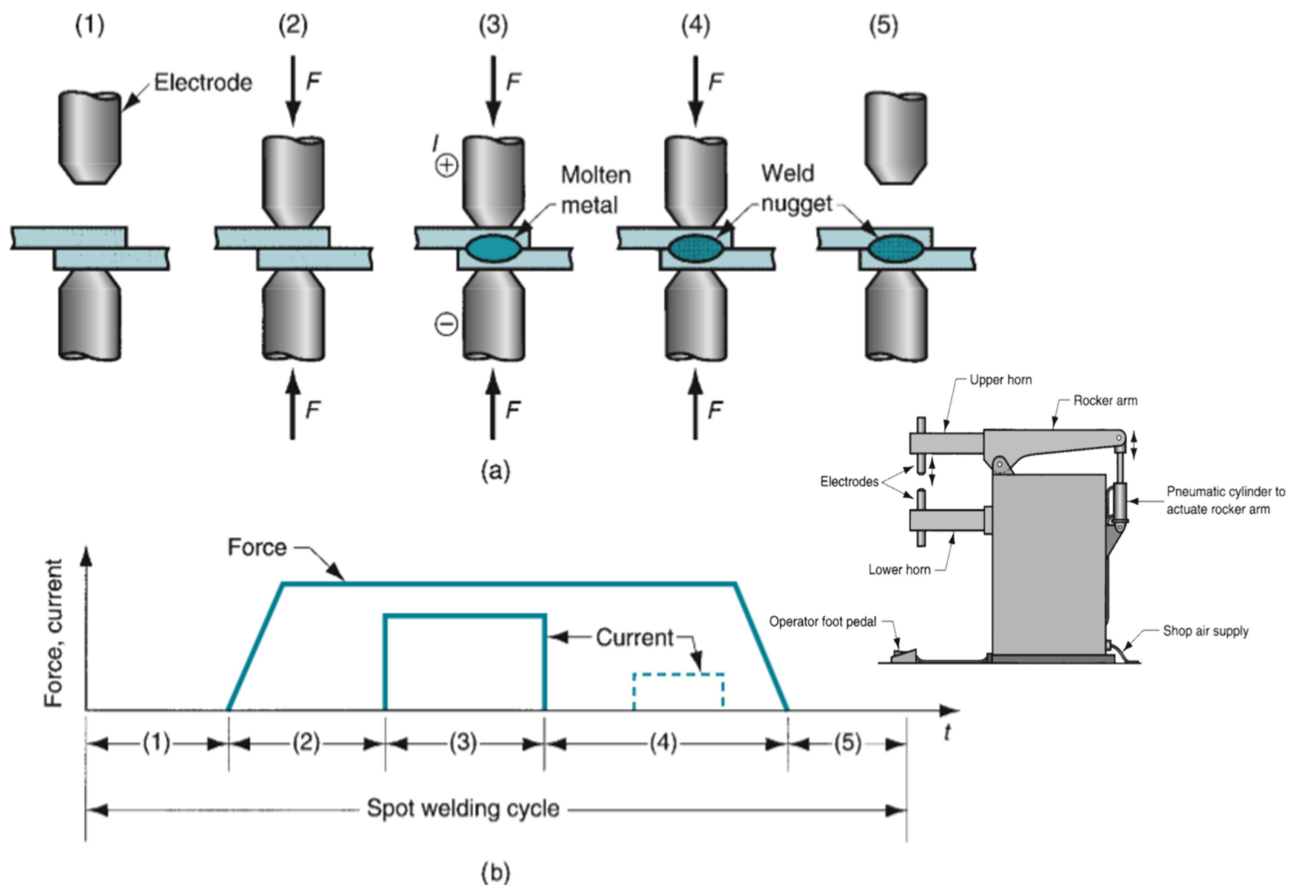


FIGURE 8. (a) Steps in a spot-welding cycle, and (b) plot of squeezing force and current during cycle. The sequence is: (1) parts inserted between open electrodes, (2) electrodes close and force is applied, (3) weld time - current is switched on, (4) current is turned off but force is maintained or increased (a reduced current is sometimes applied near the end of this step for stress relief in the weld region), and (5) electrodes are opened, and the welded assembly is removed.

The second group is noted for superior wear resistance. As in most manufacturing processes, the tooling in spot welding gradually wears out as it is used. Whenever practical, the electrodes are designed with internal passageways for water cooling. Because of its widespread industrial use, various machines and methods are available to perform spot-welding operations. The equipment includes rocker-arm and press-type spot-welding machines, and portable spot-welding guns. Rocker-arm spot welders, shown in Figure 8, have a stationary lower electrode and a movable upper electrode that can be raised and lowered for loading and unloading the work. The upper electrode is mounted on rocker arm whose movement is controlled by a foot pedal operated by the worker. Modern machines can be programmed to control force and current during the weld cycle. The upper electrode has a straight-line motion provided by a vertical press that is pneumatically or hydraulically powered. The press action permits larger

forces to be applied, and the controls usually permit programming of complex weld cycles. The previous two machine types are both stationary spot welders, in which the work is brought to the machine. For large, heavy work it is difficult to move and position the part into stationary machines. For these cases, portable spot-welding guns are available in various sizes and configurations. These devices consist of two opposing electrodes contained in a pincer mechanism. Each unit is lightweight so that it can be held and manipulated by a human worker or an industrial robot. The gun is connected to its own power and control source by means of flexible electrical cables and air hoses. Water cooling for the electrodes, if needed, can also be provided through a water hose. Portable spot-welding guns are widely used in automobile final assembly plants to spot weld car bodies.

Resistance Seam Welding (RSEW), the stick-shaped electrodes in spot welding are replaced by rotating wheels, as shown in Figure 9, and a series of overlapping spot welds are made along the lap joint. The process is capable of producing air-tight joints, and its industrial applications include the production of gasoline tanks, automobile mufflers, and various other fabricated sheet metal containers. Technically, RSEW is the same as spot welding, except that the wheel electrodes introduce certain complexities. Since the operation is usually carried out continuously, rather than discretely, the seams should be along a straight or uniformly curved line. Sharp corners and similar discontinuities are difficult to deal with. Also, warping of the parts becomes more of a factor in resistance seam welding, and fixtures are required to hold the work in position and minimize distortion. The spacing between the weld nuggets in resistance seam welding depends on the motion of the electrode wheels relative to the application of the weld current. In the usual method of operation, called continuous motion welding, the wheel is rotated continuously at a constant velocity, and current is turned on at timing intervals consistent with the desired spacing between spot welds along the seam. Frequency of the current discharges is normally set so that overlapping weld spots are produced. But if the frequency is reduced sufficiently, then there will be spaces between the

weld spots, and this method is termed roll spot welding. In another variation, the welding current remains on at a constant level (rather than being pulsed) so that a truly continuous welding seam is produced. These variations are depicted in Figure 10. An alternative to continuous motion welding is intermittent motion welding, in which the electrode wheel is periodically stopped to make the spot weld. The amount of wheel rotation between stops determines the distance between weld spots along the seam, yielding patterns similar to (a) and (b) in Figure 10. Seam-welding machines are similar to press-type spot welders except that electrode wheels are used rather than the usual stick-shaped electrodes. Cooling of the work and wheels is often necessary in RSEW, and this is accomplished by directing water at the top and underside of the work part surfaces near the electrode wheels.

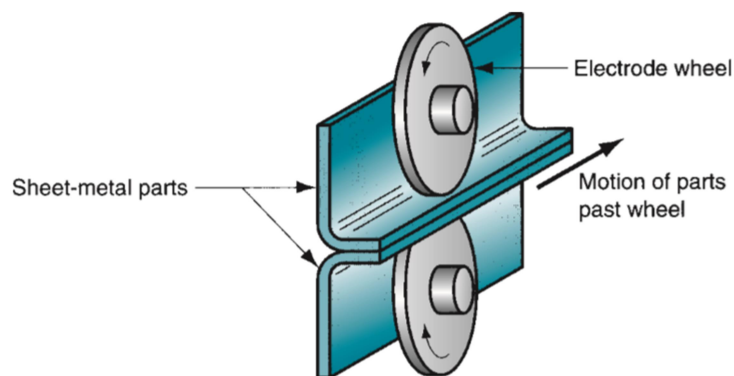


FIGURE 9. Resistance seam welding (RSEW).

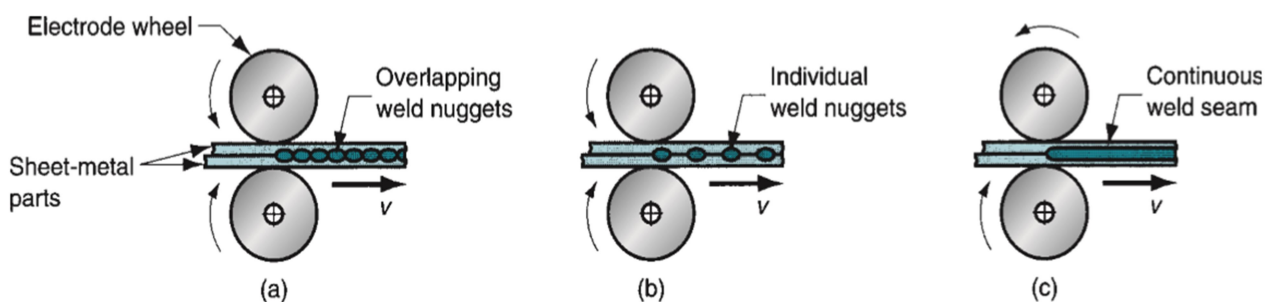


FIGURE 10. Different types of seams produced: (a) conventional resistance seam welding, in which overlapping spots are produced; (b) roll spot welding; and (c) continuous resistance seam.

Resistance Projection Welding (RPW) is an RW process in which coalescence occurs at one or more relatively small contact points on the parts. These contact points are determined by the design of the parts to be joined, and may consist of projections, embossments, or localized intersections of the parts. A typical case in

which two sheet-metal parts are welded together is described in Figure 11. The part on top has been fabricated with two embossed points to contact the other part at the start of the process. It might be argued that the embossing operation increases the cost of the part, but this increase may be more than offset by savings in welding cost. There are variations of resistance projection welding, two of which are shown in Figure 12. In one variation, fasteners with machined or formed projections can be permanently joined to sheet or plate by RPW, facilitating subsequent assembly operations. Another variation, called cross-wire welding, is used to fabricate welded wire products such as wire fence, shopping carts, and stove grills. In this process, the contacting surfaces of the round wires serve as the projections to localize the resistance heat for welding.

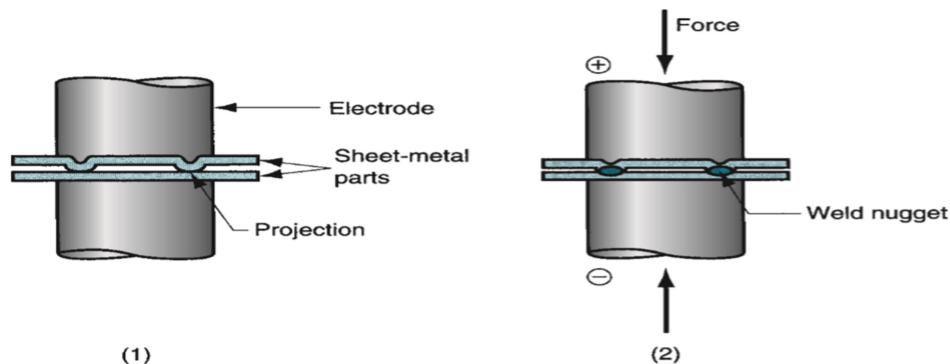


FIGURE 11. Resistance projection welding (RPW): (1) at start of operation, contact between parts is at projections; and (2) when current is applied, weld nuggets similar to those in spot welding are formed at the projections.

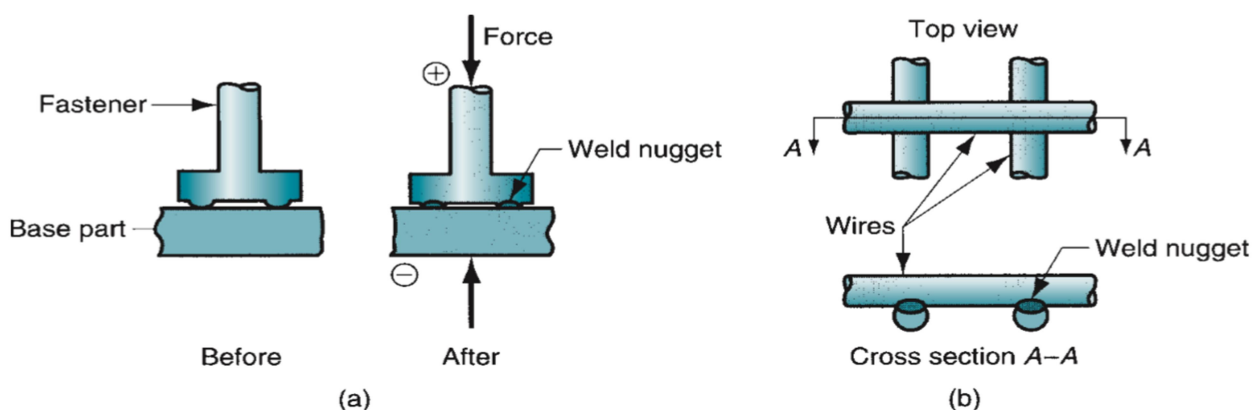


FIGURE 12. Variations of resistance projection welding: (a) welding of a machined or formed fastener onto a sheet-metal part; and (b) cross-wire welding.

Other Resistance-Welding Operations In addition to the principal RW processes described above, several additional processes in this group should be identified:

flash, upset, percussion, and high-frequency resistance welding.

3 OXYFUEL GAS WELDING

Oxyfuel gas welding (OFW) is the term used to describe the group of fusion-welding FW operations that burn various fuels mixed with oxygen to perform welding. The OFW processes employ several types of gases. Oxyfuel gas is also commonly used in cutting torches to cut and separate metal plates and other parts.

Oxyacetylene Welding (OAW) is a process performed by a high-temperature flame from combustion of acetylene and oxygen. The flame is directed by a welding torch. A filler metal is sometimes added, and pressure is occasionally applied in OAW between the contacting part surfaces (Figure 13).

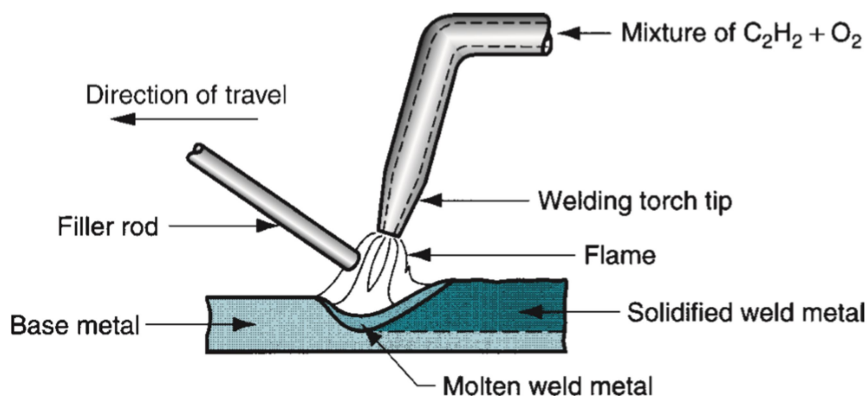


FIGURE 13. A typical oxyacetylene welding operation (OAW).

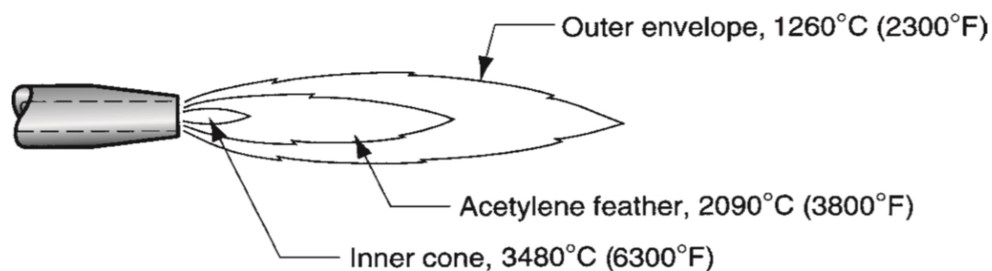


FIGURE 14. The neutral flame from an oxyacetylene torch, indicating temperatures achieved.

When filler metal is used, it is typically in the form of a rod with diameters ranging from 1.6 to 9.5 mm. Composition of the filler must be similar to that of the base metals. The filler is often coated with a flux that helps to clean the surfaces and prevent oxidation, thus creating a better weld joint. Acetylene (C_2H_2) is the most popular fuel among the OFW group because it is capable of higher temperatures than any of the others-up to $3480^{\circ}C$. The flame in OAW is produced by the chemical

reaction of acetylene and oxygen in two stages. The first stage is defined by the reaction $\text{C}_2\text{H}_2 + \text{O}_2 \rightarrow 2\text{CO} + \text{H}_2 + \text{heat}$ (a)

The products of which are both combustible, which leads to the second-stage reaction $2\text{CO} + \text{H}_2 + 1.5\text{O}_2 \rightarrow 2\text{CO}_2 + \text{H}_2\text{O} + \text{heat}$ (b)

The two stages of combustion are visible in the oxyacetylene flame emitted from the torch. When the mixture of acetylene and oxygen is in the ratio 1:1, as described in Eq. (a and b), the resulting neutral flame is shown in Figure 14. The first-stage reaction is seen as the inner cone of the flame (which is bright white), while the second-stage reaction is exhibited by the outer envelope (which is nearly colorless but with tinges ranging from blue to orange). The maximum temperature of the flame is reached at the tip of the inner cone; the second-stage temperatures are somewhat below those of the inner cone. During welding, the outer envelope spreads out and covers the work surfaces being joined, thus shielding them from the surrounding atmosphere. However, because of the temperature distribution in the flame, the way in which the flame spreads over the work surface, and losses to the air, power densities and heat transfer factors in oxyacetylene welding are relatively low.

The combination of acetylene and oxygen is highly flammable, and the environment in which OAW is performed is therefore hazardous. Some of the dangers relate specifically to the acetylene. Pure C_2H_2 is a colorless, odorless gas. For safety reasons, commercial acetylene is processed to have a characteristic garlic odor. One of the physical limitations of the gas is that it is unstable at pressures much above 1 atm (0.1 MPa). Accordingly, acetylene storage cylinders are packed with a porous filler material (such as asbestos, balsa wood, and other materials) saturated with acetone (CH_3COCH_3). Acetylene dissolves in liquid acetone; in fact, acetone dissolves about 25 times its own volume of acetylene, thus providing a relatively safe means of storing this welding gas. The welder wears eye and skin protection (goggles نظارات, gloves, and protective clothing) as an additional safety precaution الاحتياطات, and different screw threads are standard on the acetylene and oxygen cylinders and hoses to avoid accidental connection of the wrong gases. OAW equipment is relatively