Chapter 7

Radio Frequency Welding

PROCESS

Radio-frequency (RF) welding, also called high frequency welding or sealing, heat sealing, and dielectric welding or sealing, uses high frequency (13 to 100 MHz) electromagnetic energy to generate heat in polar materials, resulting in melting and weld formation after cooling. A high intensity radio signal is used to impart increased molecular motion in two similar or dissimilar polymers. This causes the materials to rise in temperature, resulting in melting and increased polymer chain mobility. Ultimately, the polymer chains of the two materials penetrate their interface and become entangled, forming a weld. RF welding is frequently used in packaging and sealing applications and is particularly suitable for the medical device industry because it uses no solvents or adhesives which are possible sources of contamination. [575]

The RF welding press has two platens - a moveable one, and a fixed one also called a bed. During the process, the press lowers the moveable platen and closes the electric circuit. The parts to be welded are placed in a set of metal dies or electrodes which are usually activated by a compressed air cylinder to apply a preset amount of pressure at the joint area. RF energy flows and the materials heat and melt. The joint cools under pressure and after the appropriate time the press opens and releases the welded assembly.

HEAT GENERATION

In radio-frequency welding, thermoplastic parts to be welded are placed under pressure between two electrodes. Energy, usually 27 MHz, is applied to the electrodes, and the resulting alternating current induces a rapidly reversing (several million times per second) electric field around the parts. Polar molecules in an electric field tend to orient in the field direction, so that the positive (or negative) end of the dipole aligns to the negative (or positive) charges in the electric field, a process called dipole polarization. Nonpolar molecules in an electric field displace electron clouds to align with the field (electronic polarization), so that centers of positive and negative charges no longer coincide. Electronic polarization is instantaneous and does not result in heat generation. Dipolar polarization, however, is not instantaneous at the high frequencies used in RF welding; as dipoles try to align with a rapidly reversing, high frequency, electric field, orientation becomes out-of-phase. The imperfect alignment causes internal molecular friction and results in generation of heat. The generated heat brings the joint interface to the melting temperature of the plastic parts. The molten materials flow together, forming molecular entanglements that produce a high strength weld.

The electrical delay between changes in electric field direction and changes in dipolar polarization is represented in Figure 7.1. An oscillating electric field, E, generates an oscillating current, *l*, within the dielectric material. At high frequencies, the two curves are out-of-phase by the phase angle, θ; the loss angle is defined as 90 θ, or δ. The amount of energy absorbed per cycle from the electric field is represented by the power factor and the dissipation factor; the power factor is defined as cos θ, and the dissipation factor or loss tangent is tan δ, a ratio of current dissipated into heat to current transmitted. The amount of dipole polarization is dependent on frequency and temperature. At low frequencies, power lost by the electric field is low due to dipole alignment with the electric field. At high frequencies, field reversal is so rapid that dipole alignment becomes out of phase, and power losses increase. Eventually, a maximum in power loss is reached, so that further frequency increases result in decreased power loss. Dipole polarization is low

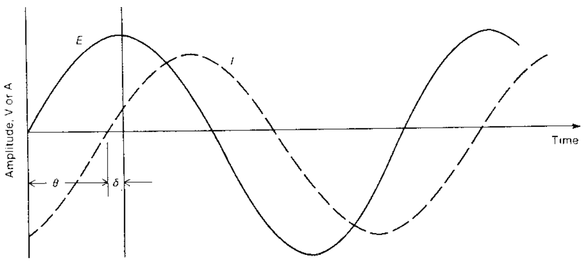

Figure 7.1 Electrical representation of dipole polarization resulting in heat generation due to imperfect alignment. An oscillating electric field, E, induced by high frequency energy, generates an oscillating current, I, within the dielectric or polar material. Dipoles are not able to complete alignment with the field in the time before the next field reversal, so that the two oscillating curves are out-of-phase by the phase angle θ; the loss angle is defined as 90 θ, or δ.

at low temperatures but increases with increasing temperature. [602]

EQUIPMENT

Radio-frequency equipment consists of three major components: a radio-frequency generator, a press, and a die or electrode. Generators commonly provide power ranging from one to 25 kW. Power requirements are determined by the welding area of the electrode and the thickness of the materials being welded. The power supply in the generator converts incoming alternating current to high-voltage direct current using solid state rectifiers; an oscillator then converts high voltage direct current to high voltage alternating current. A power control in the generator regulates the amount of power directed to the work area, and control circuits control the sequence of operations of the machine. Safety and overload protection devices automatically shut down the system if a large amount of energy becomes concentrated in a small work area. [495, 501]

The press provides pressure during the welding process and contains one fixed and one moveable platen. Pneumatic presses are most common and are used for sealing equipment providing 1 to 35 kW of power; hydraulic presses up to 50 tons are necessary for larger equipment or welding applications. Air-operated presses have adjustable 1.5 in. (3.8 cm) guide rods with bushings for accurate movement and are constructed of heavy-duty tubular steel for stabilization and ruggedness. Press components include 4.5 or 6 in. (11.4 or 15.2 cm) air or hydraulic cylinders, press speed controls with stop and stroke adjustment, a power control dial, plate and meters, air filters, and an air regulator. [495, 501]

The die or electrode is made of brass and mounted on an aluminum plate. It is built into the particular shape needed for the application. The electric field used in heating is generated at the electrode and bottom plate of the press. For sealing operations, electrodes can be designed to produce a tear seal next to the welded edge, by putting a knife edge a short distance from the welding electrode; during sealing, the knife edge penetrates the thermoplastic, and the cooled material may be separated without a secondary cutting operation.

Materials with high dielectric properties (referred to as buffers), such as phenolic laminates, electronic fishpaper, or polyester film may be used to restrict the flow of heat out of the welding area. Also, the use of a heated platen helps to stabilize the temperature during stops and starts in the welding cycle and may reduce total weld cycle time by changing dielectric properties of the materials. To compensate for material thickness variations, current detectors monitor the current during the welding cycle; when the optimum current is reached rapidly, the current detector ends the cycle, preventing overwelding or burning. If the optimum current is not reached, the detector will extend the welding cycle and prevent an underweld.

Productivity can be increased with optional equipment. With a two-sided, side-to-side shuttle, two operators work with one radio-frequency welder to compensate for the much longer loading time compared to welding time. One operator loads and unloads while the second operator's parts are being welded. An automatic press loader is a shuttle device that is used with only one operator. The unit contains two trays: when one is loaded, the other is automatically in place for the next cycle. Variable speed,

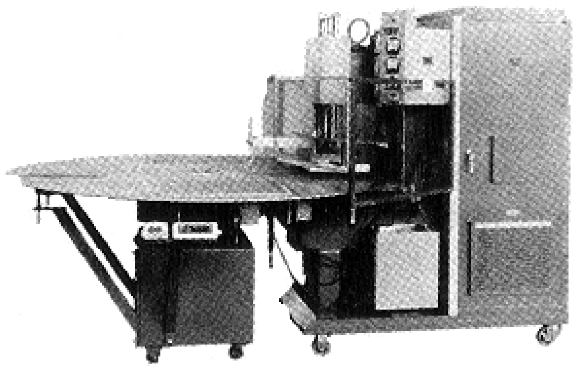

Figure 7.2 A typical radio-frequency welder.

mechanical turntables, usually seven feet (2.1 m) in diameter, can be used when several operators or a combination of operators and mechanical part feeders are loading and unloading. For sealing vinyl, rolls of material can be fed through sealers using in-line indexers. [495, 501]

A screened enclosure is not necessary for generators operating at the usual frequency of 27.12 MHz. Larger, 30 kW generators or high frequency welding operations are generally moved to a screened enclosure or shielded to reduce radiation levels and to be in compliance with FCC regulations. [501]

A typical radio-frequency welder is shown in Figure 7.2. [495, 501]

MATERIALS

Radio-frequency welding is useful for sealing and welding plastics such as polyvinyl chloride (PVC), thermoplastic polyurethanes, nylons, cellulose acetate, cellulose butyrate, cellulose acetate butyrate, PET, polyvinylidene chloride (saran), and some ABS resins. Special grades of polyethylene and polypropylene films are now available which can be sealed using RF sealing.

Materials generally considered not compatible with this method include PTFE, polycarbonate, acetal and polystyrene. Except for the films mentioned above, polypropylene and polyethylene are usually difficult to join with this method. RF welding is not generally used for welding rigid materials with high melt temperatures.

In one study utilizing samples cut from compression molded sheets, flexible PVC formed good bonds to itself, to polyurethane, and to rigid PVC. Rigid PVC did not produce good welds to itself; samples either did not melt or melted completely through before the weld could form. Rigid PVC formed good welds with flexible PVC and polyurethane. Polyurethane formed good welds to itself and to PVC, while styrenic thermoplastic elastomers formed low strength welds that could be separated by hand. [571, 495]

New experiments have used radio-frequencies of 27 MHz to join nonpolar thermoplastic parts using a composite of conductive polyaniline (PAN) and high-density polyethylene (HDPE) in the joint interface. Since dipole polarization does not occur in nonpolar materials, the conductive composite is necessary for heat generation. Power dissipated in the composite is dependent on frequency, the electric field strength, material volume, dielectric constant in a vacuum, and the dielectric constant and conductivity of the composite. [573]

PAN direct current conductivity was affected by the particle size of PAN relative to that of HDPE. Higher conductivities were obtained with PAN particle sizes over 100 times larger than those of HDPE. Because nonpolar HDPE is an insulator, small HDPE particles provide less insulation between PAN particles, resulting in more conductive paths through the composite. Highly conductive composites did not heat as well in adiabatic heating as did composites with lower conductivity; conductivities less than 0.1 siemens/cm resulted in heating to temperatures up to 275^{o}C (527^{o}F) and produced HDPE welds with good joint strength. [573]

The effect of heating time and weld pressure on the joint strength of HDPE welds using PAN composites was determined. Pressure was applied for one minute only after heating was terminated, in order to squeeze out the molten layer produced during heating. Joint strength increased greatly with increasing pressure to 1.5 MPa (218 psi), then increased only slightly as pressure increased; joint strength equivalent to that of bulk HDPE was obtained at a pressure of 3.2 MPa (464 psi) and heating time of 150 seconds. Joint strength increased almost linearly with increases in heating time; at 150 seconds (pressure 1.2 MPa, 174 psi), joint strength was 94% of bulk HDPE. [573]

ADVANTAGES AND DISADVANTAGES

Radio-frequency welding uses simple, compact equipment and requires only electricity and compressed air. No solvents or adhesives are introduced into the joint, minimizing sources of contamination.

RF welders can be used to produce more than just bonds. Dies can be used to produce what is commonly called a “tear seal”, which allows the sealed part to be pulled away from its surrounding material without a secondary cutting operation. A decorative effect can be achieved when multicolor layers are used. A hinge or folds can be introduced in a product without material distortion by producing score marks.

A disadvantage is that materials being welded must have polar groups in the molecular structure, unless a conductive PAN composite is placed in the joint interface for heat generation. [571]

APPLICATIONS

Radio-frequency sealing is commonly used in sealing thin films of PVC and vinyl for swimming pool liners and covers, inflatable toys, industrial clothing, juvenile furniture, and handbags. Seal and cut presses seal vinyl laminated fabric by first welding at low pressure, then using hydraulic pressure of 30 tons or more to cut the material with a knife-edge die. [501]

Automatic turntables and in-line indexers are used for sealing looseleaf binders, stationery supplies, car visors, and checkbook covers. Twenty kilowatt generators moving next to 20 - 50 ft. (6 - 15 m) tables are used in sealing large tarpaulins, roofing material, and signs.

Other applications include medical items such as bags and blood pressure cuffs, disposable clothing, life jackets, automobile doors and roof panels, eyeglass cases, and convertible windows. Clamshell style blister packs and other types of packaging also utilize RF welding. [495, 501]