INTRODUCTION

With major collision repair work, many of the panels on a vehicle must be replaced and welded into place. As you will learn, this requires considerable skill and care. The structural integrity of the vehicle is dependent upon how well you weld and install panels.

If not already trained, you may want to consider taking an MIG welding course in school or through another agency. Ask your instructor or guidance counselor for more information on welding courses in your school or area. Welding is an essential skill if you plan on becoming a master auto body technician. It is a good idea to become I-CAR trained and pass their Automotive MIG Welding Qualification Test to show your welding skills are competent.

JOINING METALS

There are three basic methods of joining metal together in the automobile assembly:

- Mechanical (metal fastener) methods (Figure 7-1)
- Chemical (adhesive fastening) methods

OBJECTIVES

After studying this chapter, you should be able to:

- Identify the three classes of welding.
- Explain how to use an MIG welding machine.
- Name the six basic welding techniques employed with MIG equipment.
- Describe differences between MIG electrode wires.
- Determine where and how to use resistance spot welding.
- Identify oxyacetylene welding equipment and techniques.
- Explain general brazing and soldering techniques used in a body shop.
- Describe plasma arc cutting of body panels.
- Explain plasma cutting techniques.
- List safety procedures important in each welding operation.
- Pass ASE Certification test questions on welding and cutting.
- Explain the information needed to pass I-CAR’s Welding Qualification Test.

KEY TERMS

brazing  nondestructive check  overhead welding  oxidizing flame
burn mark  plasma arc cutting  plug weld
burn-through  pressure welding  spot weld
carburizing flame  stitch weld  tack weld
continuous weld  vertical welding  weld face
DC reverse polarity  weld leg  weld penetration
destructive check  weld root  weld throat
flat welding  welding filter lens  insert
fusion welding  joint fit-up  lap spot weld
heat crayons  MIG welding  neutral flame
ASE TASK LIST

Job Skills covered in this chapter include:

PAINTING AND REFINISHING TEST (B2)
TASK LIST

A. Surface Preparation
1. Remove, assess, and store trim and moldings.
2. Identify type of metal and apply suitable metal treatment or primer.

NONSTRUCTURAL ANALYSIS AND DAMAGE REPAIR TEST (B3) TASK LIST

A. Preparation
3. Remove outside trim and moldings as necessary; store reusable parts.
4. Remove damaged or undamaged inside trim and moldings as necessary; store reusable parts.
5. Protect panels and parts adjacent to repair area, to prevent damage during repair.
6. Remove repairable plastics and other parts that are recommended for off-vehicle repair.

B. Outer Body Panel Repairs, Replacements, and Adjustments
7. Determine the extent of damage to aluminum body panels; repair, weld, or replace in accordance with manufacturers’ specifications.
8. Remove, replace, and align bumpers, reinforcements, guards, isolators, and mounting hardware.
9. Weld cracked or torn steel body panels; reweld broken welds; replace molding studs.
10. Remove damaged sections of steel body panels; weld in replacements in accordance with manufacturers’/industry specifications.
11. Determine the correct type of weld (continuous, stitch/pulse, tack, plug, spot, etc.) for each specific welding operation.
12. Identify the causes of spits and sputters, burn-through, lack of penetration, cracks in metal, porosity, incomplete fusion, excessive spatter, distortion, waviness of bead, and failure of wire to feed; make necessary adjustments.
13. Identify proper cutting process for different materials and locations in accordance with manufacturers’ recommendations.

C. Metal Finishing and Body Filling
14. Heat shrink stretched panel areas to proper contour.

D. Welding and Cutting
15. Identify weldable and nonweldable materials used in vehicle construction.
16. Understand the limitations of welding and cutting high-strength steels and other metals.
17. Determine correct welding process [GMAW (MIG), compression/resistance spot, oxyacetylene, GTAW (TIG)], electrode, wire type, diameter, and gas to be used in specific welding situations.
18. "Tune" the MIG welder by adjusting for the proper electrode stickout, voltage, polarity, flow rate, and wire speed required for the material being welded.
19. Identify safety considerations: Eye protection, proper clothing, shock hazards, fumes, M, S, D, S, etc. before beginning any welding operation.

6. Apply knowledge of the proper procedures for safely handling gas cylinders.
7. Insure proper work clamp (ground) location.
8. Use the proper gun-to-joint angle, and direction of gun travel, for welds being made in all positions.
9. Protect vehicle components, including computers and other electronic modules, from possible welding and cutting damage.
10. Clean the metal to be welded; assure good metal fit-up; apply weld-through primer.
11. Perform the correct joint type (butt, lap, etc.) for the weld being made.
12. Identify the causes of spits and sputters, burn-through, lack of penetration, cracks in metal, porosity, incomplete fusion, excessive spatter, distortion, waviness of bead, and failure of wire to feed; make necessary adjustments.
13. Identify proper cutting process for different materials and locations in accordance with manufacturers’ recommendations.

STRUCTURAL ANALYSIS AND DAMAGE REPAIR TEST (B4) TASK LIST

A. Frame Inspection and Repair
8. Remove and replace damaged frame horns, side rails, cross members, and front or rear sections.
9. Repair or replace weakened or cracked frame members in accordance with vehicle manufacturers’/industry standards.

B. Unibody Inspection, Measurement, and Repair
15. Determine the extent of damage to structural steel body panels; repair, weld, or replace in accordance with vehicle manufacturers’ specifications.
16. Remove damaged sections of structural steel body panels, and weld in replacements in accordance with vehicle manufacturers’ specifications.

D. Metal Welding and Cutting
1. Identify weldable and nonweldable materials used in vehicle construction.
2. Understand the limitations of welding and cutting high-strength steels and other metals.
3. Determine correct welding process [GMAW (MIG), compression/resistance spot, GTAW (TIG)], electrode, wire type, diameter, and gas to be used in specific welding situations.
4. "Tune" the MIG welder by adjusting for proper electrode stickout, voltage, polarity, flow rate, and wire speed required for the material being welded.

5. Identify safety considerations: eye protection, proper clothing, shock hazards, fumes, etc. before beginning any welding operation.

6. Understand the proper procedures for safely handling gas cylinders.

7. Insure proper work clamp (ground) location.

8. Use the proper gun-to-joint angle, and the direction of gun travel, for welds being made in all positions.

9. Protect vehicle components, including computers and other electronic modules, from possible damage from welding and cutting operations.

10. Clean the metal to be welded; assure good metal fit-up; apply weld-through primer.

11. Perform the correct type of joint (butt, lap, etc.) for the weld being made.

12. Determine the correct type of weld (continuous, stitch/pulse, tack, plug, spot, etc.) for each specific welding operation.

13. Identify the causes of spits and spatters, burn-through, lack of penetration, cracks in metal, porosity, incomplete fusion, excessive spatter, distortion, waviness of bead, and failure of wire to feed; make necessary adjustments.

14. Identify the proper cutting process (abrasive, plasma arc, oxyacetylene) for different materials and locations in accordance with manufacturers' recommendations.

**Figure 7-1** Mechanical joining methods use threaded or non-threaded fasteners, which are heavier and less dependable than a welded joint.

- **Welding (molten metal) methods** (Figure 7-2)

  **Welding** is a method of repair in which heat is applied to pieces of metal to fuse them together into the shape desired. Welding can be divided into three main categories:

  - **Pressure welding.** The metal is heated to a softened state by electrodes. Pressure is applied, and the metal is joined. Of the various types of pressure welding, electric resistance welding (spot welding) is an indispensable method used in automobile manufacturing and to a lesser degree in repair operations.

  - **Fusion welding.** Pieces of metal are heated to the melting point, joined together (usually with a filler rod), and allowed to cool.

  - **Braze welding.** Metal with a melting point lower than the base metal to be joined is melted over the joint of the pieces being welded (without fusing pieces of base metal). Braze welding is classified as either soft or hard brazing, depending on the temperature at which the brazing material melts. **Soft brazing** is done with brazing material that melts at temperatures below 850 degrees Fahrenheit (455 degrees Celsius). **Hard brazing** is done with brazing materials that melt at temperatures above 850 degrees Fahrenheit (455 degrees Celsius).

  Shown in Table 7-1, there are distinct welding methods within each respective category. Many of these methods can be used in the auto body shop. Gas metal arc welding is the preferred method.

**WELD TERMINOLOGY**

The **weld root** is the part of the joint where the wire electrode is directed. The **weld face** is the exposed surface of the weld on the side that has been welded.
Visible **weld penetration** is indicated by the height of the exposed surface of the weld on the back side. Full weld penetration is needed to assure maximum weld strength.

A **burn mark** on the back of a weld is an indication of good weld penetration. **Burn-through** results from penetrating too much into the lower base metal which burns a hole through the back side of the metal.

Fillet weld parts include the following. The **weld legs** are the width and height of the weld bead. The **weld throat** refers to the depth of the triangular cross section of the weld.

**Joint fit-up** refers to holding work pieces tightly together, in alignment, to prepare for welding. It is critical to the replacement of body parts!

**WELDING CHARACTERISTICS**

Joint welding is indispensable in the restoration of collision-damaged vehicles. The characteristics of welding can be summarized as follows:

- Since the shape of welding joints is limitless, it is the perfect method for joining a vehicle structure, while still maintaining body integrity.
- Weight can be reduced (no fasteners are necessary).
- Air and water tightness are excellent.
- Production efficiency is very high.
- Strength of a welded joint is greatly influenced by the level of skill of the operator.
- Surrounding panels will warp if too much heat is used.
WELDING IN THE AUTO BODY SHOP

New welding techniques and equipment have entered the auto body repair picture, replacing the once popular arc and oxyacetylene processes (Figure 7-3). New steel alloys used in today’s cars cannot be welded properly by these two processes. Presently gas metal arc welding (GMAW)—better known as metal inert gas (MIG) welding—offers more advantages than other methods for welding high-strength steels (HSS) and high-strength, low-alloy (HSLA) steel component parts used in modern cars. Most of the applications of HSS and HSLA steels are confined to body structures, reinforcement gussets, brackets, and supports, rather than large panels or outer skin panels.

The advantages of MIG welding (Figure 7-4) over conventional stick electrode arc welding (Figure 7-5) are so numerous that manufacturers now recommend it almost exclusively. MIG welding is recommended by all OEMs, not only for HSS and unibody repair, but for all structural collision repair. This recommendation extends also to independent collision repair shops.

Here are some of the advantages of MIG welding:

- MIG welding is easier to learn than arc or gas welding. The typical welder can learn to use MIG welding equipment with proper training. Moreover, experience shows that even an average MIG welder can produce higher quality welds faster and more consistently than a highly skilled welder using older stick electrode welds.
- MIG welding produces 100 percent fusion in the parent metals. This means MIG welds can be dressed or ground down flush with the surface (for cosmetic reasons) without loss of strength.
- Low current can be used for thin metals. This prevents heat damage to adjacent areas that can cause strength loss and warping.
- The arc is smooth and the weld puddle small, so it is easily controlled (Figure 7-6). This ensures maximum metal deposit with minimum splatter.
MIG welding is more tolerant of gaps and misfits. Several gaps can be spot welded immediately (no slag to remove) by making several spots on top of each other. Therefore, the area can be easily refinished.

Almost all steels can be welded with one common type of weld wire. What is in the machine is generally right for any job.

Metals of different thicknesses can be welded with the same diameter of wire. Again, what is in the machine is right for almost any job.

The MIG welder can control the temperature of the weld and the time the weld takes place.

With MIG welding, the small area to be welded is heated for a short period of time, thereby reducing metal fatigue, warpage, and distortion of the panel. Vertical and/or overhead welding is possible because the metal is molten for a very short time.

Portable resistance spot welding is also recommended today for some repairs (Figure 7-7). This type of equipment is used to form spot weld attachments like the production welds. To use this kind of spot welding equipment, you must install the proper extensions and electrodes on the welder to provide access to the area being welded. The clamping force on a squeeze-type resistance spot welder must be properly adjusted. On some equipment, the amperage, current flow, and timing are all made with one adjustment. After the adjustments are made, the spot welder is positioned over the panels being joined, making sure the electrodes are directly opposite to each other. The trigger is squeezed and the spot weld takes place.

The resistance spot welder, which probably requires the least skill to operate, provides very fast, high-quality welds while maintaining the best control of temperature buildup in adjacent panels and structure. When reference is made to resistance type spot welders, it generally describes the type of welding that requires the actual weld to take place on both sides of all panels at the same time. It normally does not mean the type of spot weld that welds panels together from the same side at the same time. Opposite side spot welding is a structural weld.

Be sure to consult the car manufacturer's recommendations in the vehicle's service manual before welding. When replacing body panels, all the new welds should be similar in size to the original factory welds. Except when spot welding, the number of replacement welds should be the same as the original number of welds in production. Strength and durability requirements differ depending on the location of the part that is to be welded to the body.

The manufacturer decides what is the most appropriate welding method (Figure 7-8) by first determining the intended use, the physical characteristics, and the location of the part.

**WARNING**

Always follow service manual recommendations when welding. This will assure structural integrity.

It is essential that appropriate welding methods, which do not reduce the original strength and durability of the body, are used when making repairs. This is accomplished if the following basic points are observed:

- **Try to use either spot welding or MIG/MAG [metal inert gas/metal active gas] welding.**
- **Do not** braze any body components other than those brazed at the factory.
- **Do not** use an oxyacetylene torch for welding late model auto bodies.
FIGURE 7-8 Compare the welding methods used in vehicle production. (Courtesy of Nissan Motor Corp.)
Regardless of the type of welding, you must properly clean the surface before starting the weld. Remove all surface materials back to the bare metal (Figure 7-9). When dirt, rust, sealers, paint, or other materials are left in the area of the weld, they will burn during the application of heat. The ash or oxidized material can become a part of the weld. The dirt and foreign material cause the weld to be weakened. If the weld fails, it could endanger the occupants of the car or truck.

7.1 MIG WELDING

MIG welding became popular in body shops when auto manufacturers began using thin-gage, high-strength, low-alloy (HSLA) steels. Car makers insisted that the only correct way to weld HSLA and other thin-gage steel was with MIG (or the similar gas metal arc welding [GMAW] system). And once the MIG welder was in place, it was easy to see that it provided clean, fast welds for all applications. Welding a rear quarter panel with an oxyacetylene welder averages about 4 hours. An MIG welder can do the same job in about 40 minutes.

MIG welding is not limited to body repairs alone. It is also ideal for exhaust work, repairing mechanical supports, installing trailer hitches and truck bumpers, and any other welds that would be done with either an arc or gas welder. In addition, it is possible to weld aluminum castings, like cracked transmission cases, cylinder heads, and intake manifolds.

MIG PRINCIPLES AND CHARACTERISTICS

MIG welding uses a welding wire that is fed automatically at a constant speed as an electrode. A short arc is generated between the base metal and the wire. The resulting heat from the arc melts the welding wire and joins the base metals together. Since the wire is fed automatically at a constant rate, this method is also called semiautomatic arc welding.

During the welding process (Figure 7-10), either inert gas or active gas shields the weld from the atmosphere and prevents oxidation of the base metal. The type of inert or active gas used depends on the base material to be welded. For most steel welds, carbon dioxide (CO₂) is used as the shield gas (Figure 7-10).

**FIGURE 7-9** Make sure the surfaces to be welded are completely free of rust and scale contaminants loosened by grinding, sanding, or sandblasting.

**FIGURE 7-10** Study principles of MIG welding, especially hook-up and major welder parts. [Courtesy of Toyota Motor Corp.]
MIG welding is sometimes called carbon dioxide arc welding. Actually, MIG (metal inert gas) welding uses a fully inert gas, such as argon or helium, as a shield gas. Since carbon dioxide gas is not a completely inert gas, it is more accurately called MAG (metal active gas) welding. Although most auto body shop welding is done with carbon dioxide gas as the shield gas, the term MIG is used to describe all gas metal arc welding processes. In fact, many welders on the market can use carbon dioxide (a semiaactive gas) or argon (an inert gas) by simply changing the gas cylinder.

7–11). Another common shielding gas mixture is 75 percent argon and 25 percent carbon dioxide. This latter mixture is usually referred to as C-25 gas.

With aluminum, either pure argon gas or a mixture of argon and helium is used, depending on the alloy and the thickness of the material. It is even possible to weld stainless steel by using argon gas with a little oxygen (between 4 and 5 percent) added.

MIG flux core wire has its own flux contained in a tubular electrode and does not require a shielding gas. As with stick welding, the flux forms slag that must be chipped off. Flux core electrode wire is not convenient for most collision repair work. It takes more time to clean the weld.

MIG welding uses the short circuit arc method that is a unique method of depositing molten drops of metal onto the base metal. Welding of thin sheet metal for automobiles can cause welding strain, blow holes, and warped panels. To prevent these problems, it is necessary to limit the amount of heat near the weld. The short circuit arc method uses very thin welding rods, a low current, and low voltage. By using this technique the amount of heat introduced into the panels is kept to a minimum and penetration of the base metal is quite shallow.

As shown in Figure 7–12, the end of the wire is melted by the heat of the arc and forms into a drop. The drop then comes in contact with the base metal and creates a short circuit. When this happens, a large current flows through the metal and the shorted portion is torn away by the pinch force or burnback, which re-establishes the arc. The bare wire electrode is fed continuously into the weld puddle at a controlled, constant rate, where it short circuits, and the arc goes out. While the arc is out, the puddle flattens and cools; but the wire continues to feed, shorting to the workpiece again. This heating and cooling happens on an average of 100 times a second. The metal is transferred to the workpiece with each of these short circuits.

If current is flowing through a cylindrical-shaped fluid (in this case molten metal) or current is flowing through an arc, the current is pulled toward the weld. This works as a constrictive force in the direction of the center of the cylinder. This action is known as the pinch effect, and the size of the force is called the pinch force (Figure 7–13).

In summary, the MIG welding process works like this:

- At the weld point, the wire undergoes a split-second sequence of short circuiting, burnback, and arcing (Figure 7–14).
- Each sequence produces a short arc transfer of a minute drop of electrode metal from the tip of the wire to the weld puddle.
- A gas curtain or shield surrounds the wire electrode. This gas shield prevents contamination from the atmosphere and helps stabilize the arc.
- The continuously fed electrode wire contacts the work and sets up a short circuit, and resistance heats the wire and the weld site.
- As the heating continues, the wire begins to melt and thin out or neck down.
- Increasing resistance in the neck accelerates the heating in this area.
- The molten neck burns through, depositing a puddle on the workpiece and starting the arc.
- The arc tends to flatten the puddle and burn back the electrode.

- With the arc gap at its widest, it cools, allowing the wire feed to move the electrode closer to the work.
- The short end starts to heat up again, enough to further flatten the puddle but not enough to keep the electrode from recontacting the workpiece. This extinguishes the arc, re-establishes the short circuit, and restarts the process.
- This complete cycle occurs automatically at a frequency ranging from 50 to 200 cycles a second.

7.2 MIG WELDING EQUIPMENT

Most MIG welding equipment for collision repair work is considered semiautomatic. This means that the machine's operation is automatic, but the gun is hand controlled. Before starting to weld, the operator sets

- Voltage for the arc
- Wire speed
- Shielding gas flow rate

Then the operator has complete freedom to concentrate entirely on the weld site, the molten puddle, and whatever welding technique that is used.

Regardless of the type of MIG equipment used, it will comprise the following basic components (Figure 7-15):

- Supply of shielding gas with a flow regulator to protect the molten weld pool from contamination
- Wire/feed control to feed the wire at the required speed
- Spool of electrode wire of a specified type and diameter
- MIG type of welder machine connected to an electrical power supply
- Work cable and clamp assembly
- Welding gun and cable assembly that the welder holds to direct the wire to the weld area

Fine diameter welding wires are used in collision repair and typically range from .025 inch (0.397 mm) through .030 inch (0.793 mm). This is roughly equivalent in diameter to ultrafine leads in today's mechanical pencils. A wire that is becoming more commonly used today is .025 inch (0.397 mm). Once a specialty wire, it is now stocked by most wire manufacturers. These small diameter wires can be used at low currents (10 to 20 amps) and voltages (120 volts), thus greatly reducing heat input to the base material. The welding wire must carry a minimum specification of AWS-ER70-6.

Because of the power demands in this process, it is necessary to use a constant potential, constant
I-CAR worked with the American Welding Society to develop industry standards for auto body welding. You may want to consider enrolling in an I-CAR welding class to upgrade your skills.

Voltage power source (Figure 7–16). The controls are a voltage adjustment and wire feed speed adjustment. Some optional controls available on this type of equipment (Figure 7–17) are a spot control and pulse control.

MIG spot welding is termed consumable spot welding because the welding wire is consumed in the weld puddle. Consumable spot welds can be made in a variety of methods and in all positions using various nozzles equipped with this option.

When you are spot welding different thicknesses of materials, the lighter gauge material should always be spotted to the heavy material.

Spot welding usually requires greater heat to the weld than continuous or pulse welding. It is best to use sample materials when setting the controls for spot welding. To check a spot weld, pull the two pieces apart. A good weld will tear a small hole out of the bottom piece. If the weld pulls apart easily, increase the weld time or heat. After each spot is complete, the trigger must be released and then pulled for the next spot.

MIG spot has the advantage of an easily grindable crown. The procedure does not leave any depression requiring a fill.

The pulse control allows continuous seam welding on the material with less chance of burn-through or distortion. This is accomplished by starting and stopping the wire for preset times without releasing the trigger. The weld "on" time and weld "off" time can be set for the operator’s preference and the metal thickness.

The burnback control on most MIG gives an adjustable burnback of the electrode to prevent it from sticking in the puddle at the end of a weld.

In MIG welding the polarity of the power source is important in determining the penetration to the workpiece. DC power sources used for MIG welding typically use DC reverse polarity. DC reverse polarity means the wire (electrode) is positive and the workpiece is negative. Weld penetration is greatest using this connection.

Weld penetration is also greatest using CO₂ gas. However, CO₂ gives a harsher, more unstable arc, which leads to increased spatter. So when welding on thin materials, it is preferable to use argon/CO₂ (Figure 7–18).
7.3 MIG OPERATION METHODS

To match MIG welding power to the available input voltage, follow the procedure prescribed on the machine or in the manufacturer's manual (Figure 7-19). Handle the cylinder of shielding gas with care. It might be pressurized to more than 2,000 pounds per square inch (13,800 kPa). Chain or strap the cylinder.

Voltage adjustment and wire feed speed must be set according to the diameter of the wire being used and metal thickness. It should be noted that when setting these parameters, the manufacturer's recommendations should be followed to reach approximate settings. When rough parameters are selected, change only one variable at a time until the machine is fine tuned for an optimum welding condition. MIG welders can be tuned in using both visual and audio signals.

WELDING LENS

A welding filter lens, sometimes called filter plate, is a shaded glass welding helmet insert for protecting your eyes from ultraviolet burns. The lenses are graded with numbers, from 4 to 12. The higher the number, the darker the filter. The American Welding Society (AWS) recommends grade 9 or 10 for MIG welding steel.

Note that there are self-darkening filter lenses available that instantly turn dark when the arc is struck. There is no need to move the face shield up and down.

FIGURE 7-19 Check the manufacturer's manual before hooking up equipment.

FIGURE 7-20 (A) Install the shielding gas cylinder with care and (B) chain or strap it in place.

FIGURE 7-21 Do not crossthread or strip fit when installing a regulator on a cylinder.
to a support sturdy enough to hold it securely to the MIG machine (Figure 7-20). Install the regulator, making sure to observe the recommended safety precautions (Figure 7-21).

When the clamp is attached to clean metal on the vehicle (Figure 7-22) near the weld site, it completes the welding circuit from the machine to the work and back to the machine. This clamp is not referred to as a ground cable or ground clamp. The ground connection is for safety purposes and is usually made from the machine’s case to the building ground through the third wire in the electric input cable.

Consult the manufacturer’s manual as to the specific procedure for assembling, installing, and adjusting the wire feeder components (Figure 7-23). In general, the adjustment of the wire feeder can be done as follows:

- Mount the wire. Feed the wire manually for about 12 inches (305 mm), making sure that it travels freely through the gun assembly.
- A correct setting on the drive rollers will assure just enough pressure on the wire to pull it off the wire spool and through the gun/cable assembly (Figure 7-24). The tension must be set so that the wire will slip at the rollers when the wire is stopped at the nozzle, but tight enough to withstand a 30 to 40 degree deflection. If too much pressure is applied, the wire will be deformed, creating a spiral effect through the liner and erratic feed.
- Stopping the wire at the tip with this much pressure will also cause the wire to bird-nest between the rollers and cable entrance. The tension on the wire spool spindle should also be set so that the wire can be pulled off easily but just tight enough to stop the spool from free wheeling when the trigger is released (Figure 7-25).

The proper handling of any welding equipment is an essential ingredient in successful welding. When tuning the MIG welder for any given welding job, you have to deal with a number of parameters, meaning values that are variable: input voltage to the welding equipment, welding current, arc voltage, tip-to-base metal distance, torch angle, welding direction, shield gas flow volume, welding speed, and
TABLE 7-2: RELATIONSHIP BETWEEN WIRE DIAMETER, PANEL THICKNESS, AND WELDING CURRENT

<table>
<thead>
<tr>
<th>Wire Diameter</th>
<th>1/64&quot;</th>
<th>1/32&quot;</th>
<th>Less Than 3/64&quot;</th>
<th>3/64&quot;</th>
<th>1/16&quot;</th>
<th>3/32&quot;</th>
<th>1/8&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/64&quot;</td>
<td>20-30A</td>
<td>30-40A</td>
<td>40-50A</td>
<td>50-60A</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1/32&quot;</td>
<td>—</td>
<td>—</td>
<td>40-50A</td>
<td>50-60A</td>
<td>60-90A</td>
<td>100-120A</td>
<td>—</td>
</tr>
<tr>
<td>More Than 1/32&quot;</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>60-90A</td>
<td>100-120A</td>
<td>120-150A</td>
</tr>
</tbody>
</table>

**FIGURE 7-26** These are the three most important variables for a good weld: penetration depth, excess metal height, and bead width. *(Courtesy of Toyota Motor Corp.)*

wire speed. Most manufacturers of MIG welders provide tables that show the variable control parameters that apply to their machines.

**MIG WELDING CURRENT**

Welding current affects the base metal penetration depth (Figure 7-26), the speed at which the wire is melted, arc stability, and the amount of weld spatter. As the electrical current is increased, the penetration depth, excess metal height, and bead width also increase (Table 7-2).

**MIG ARC VOLTAGE**

Good welding results depend on a proper arc length. The length of the arc is determined by the arc voltage. When the arc voltage is set properly, a continuous light hissing or cracking sound is emitted from the welding area.

When the arc voltage is high, the arc length increases, the penetration is shallow, and the bead is wide and flat.

When the arc voltage is low, the arc length decreases, penetration is deep, and the bead is narrow and dome shaped (Figure 7-27).

**FIGURE 7-27** Note how arc voltage affects the bead shape.

Since the length of the arc depends on the amount of voltage, voltage that is too high will result in an overly long arc and an increase in the amount of weld spatter. A sputtering sound and no arc means that the voltage is too low.

**MIG TIP-TO-BASE METAL DISTANCE**

The tip-to-base distance (Figure 7-28) is also an important factor in obtaining good welding results. The
reduce the shield effect. If there is not enough gas, the shield effect will also be reduced. Adjustment is made in accordance with the distance between the nozzle and the base metal, the welding current, welding speed, and welding environment (nearby air currents). The standard flow volume is approximately 1½ to 1½ cubic inches (0.022 to 0.024 liters) per minute or 15 to 25 cubic feet (420 to 700 cubic liters) per hour.

**MIG WELDING SPEED**

If you weld at a rapid pace, the penetration depth and bead width decreases, and the bead is dome shaped. If the speed is increased even faster, undercutting (weld surface lower than base metal) can occur. Welding at too low a speed can cause burn-through holes. Ordinarily, welding speed is determined by base metal panel thickness and/or voltage of the welding machine (Table 7-3).

**MIG WIRE SPEED**

An even, high-pitched buzzing sound indicates the correct wire-to-heat ratio producing a temperature in the 9,000 degrees Fahrenheit (4,986 Celsius) range. Visual signs of the correct setting occur when a steady reflected light starts to fade in intensity as the arc is shortened and wire speed is increased.

If the wire speed is too slow (Figure 7-31), a hiss and a plop sound will be heard as the wire melts away from the puddle and deposits the molten gob back. The visual signal will be a much brighter reflected light.

Too much wire speed will choke the arc. More wire is being deposited than the heat and puddle can absorb. The result is spitting and sputtering as the wire melts into tiny balls of molten metal that fly away from the weld. The visual signal is a strobe light arc effect.

Before this critical ratio can be obtained, a thorough understanding of what is happening to produce these signals is essential.

When the trigger is first activated, a solid steel wire makes its initial contact with a solid steel plate. Prior to contact, the wire has been charged with current and the gas flow has been started (Figure 7-32). The first contact produces tiny sparks of oxide being burned off the wire and base metal.

Immediately after the oxide sparks, tiny molten balls are produced as the wire melts prior to having a molten puddle that will absorb them. Once the heat creates the puddle, the balls stop. A consistent transfer and sound with only oxide sparks are present as they burn off the wire and base metal during the weld process.

In slow motion, after the arc transfer has been started, an on-off action occurs. Every time the metal is deposited a plop is heard. When it pulls away, a hiss is heard. Speeded up to 200 plops and hisses per second, it creates a smooth buzz, like the sound of bacon frying in a pan.

When welding overhead, the danger of having too large a puddle and ball are obvious. The ball is pulled by gravity down onto the contact tip or into the gas nozzle where it can create serious problems. Therefore, overhead welding should always be done with a higher wire speed with the arc and ball kept tiny and close together. Pressing the gas nozzle against the work insures that the wire is not moved out of the puddle. If it is moved out, the balls are produced by melting wire until a new puddle is formed to absorb them.

<table>
<thead>
<tr>
<th>Panel Thickness</th>
<th>Welding Speed (ln./min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/32&quot;</td>
<td>41-1/12-45-9/32</td>
</tr>
<tr>
<td>More Than 1/32&quot;</td>
<td>39-3/8</td>
</tr>
<tr>
<td>3/64&quot;</td>
<td>35-7/16-39-3/8</td>
</tr>
<tr>
<td>1/16&quot;</td>
<td>31-1/2-33-15/32</td>
</tr>
</tbody>
</table>

**FIGURE 7-31** If the wire speed is too slow, increase the dial setting on the welder.

**FIGURE 7-32** Prior to contact, the wire has been charged and the gas flow started.
<table>
<thead>
<tr>
<th>Welding Variables to Change</th>
<th>Penetration</th>
<th>Deposition Rate</th>
<th>Bead Size</th>
<th>Bead Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desired Changes</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
</tr>
<tr>
<td>Current and Wire Feed Speed</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
</tr>
<tr>
<td>Voltage</td>
<td>Little effect</td>
<td>Little effect</td>
<td>No effect</td>
<td>No effect</td>
</tr>
<tr>
<td>Travel Speed</td>
<td>Little effect</td>
<td>Little effect</td>
<td>No effect</td>
<td>No effect</td>
</tr>
<tr>
<td>Stickout</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
<td>Decrease</td>
</tr>
<tr>
<td>Wire Diameter</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
</tr>
<tr>
<td>Shield Gas Percent CO₂</td>
<td>Increase</td>
<td>Decrease</td>
<td>No effect</td>
<td>No effect</td>
</tr>
<tr>
<td>Torch Angle</td>
<td>Backhand to 25°</td>
<td>Forehand</td>
<td>No effect</td>
<td>No effect</td>
</tr>
</tbody>
</table>

Normal buildup of oxide sparks in the gas nozzle area must be carefully removed before they fall inside and short out the nozzle. Balls caused by too slow a wire speed must also be removed before a short is formed.

As a summary, Table 7-4 outlines the various effects of several welding parameters and the changes necessary to alter a variety of weld characteristics.

**MIG Gun Nozzle Adjustment**

The guns used on automotive MIG welders serve two main functions:

1. To provide proper gas protection
2. To feed the wire into the arc at the right speed

If the insulation is bypassed by accidentally grounding the body of the gun, the power intended for the wire is transferred to the gas nozzle, causing the nozzle to burn up. Welding on dirty or rusty material can cause heavy bombardment into the nozzle and will require immediate cleaning if proper welding performance is to be achieved. To successfully weld on a poor, rusty surface, slow the wire speed. Set the burnback control to its maximum and tap the trigger floating the ball on and off the material.

Of the four main components in an MIG welder, the nozzle area is the most crucial. The wire feed delivery is second. A clogged or damaged liner will cause erratic wire speed and produce molten balls that, in turn, will short out the gas nozzle.

To summarize the basic adjustment procedure of the gas nozzle, proceed as follows:

- **Arc generation.** Position the tip of the gun near the base metal. When the gun switch is activated (Figure 7-33), the wire is fed at the same time as the shield gas. Bring the end of the wire in contact with the base metal and create an arc. If the distance between the tip and the base metal is shortened a little, it will be easy to generate an arc (Figure 7-34). If the end of the wire forms a large ball, it will be difficult to generate an arc, so quickly cut off the end of the wire with a pair of wire cutters (Figure 7-35).
- **Spatter treatment.** Remove weld spatter promptly. If it adheres to the end of the nozzle, the shield gas will not flow properly and a poor weld will result. Antispatter compounds are available that...
reduce the amount of spatter that adheres to the nozzle (Figure 7-36). Weld spatter on the tip will prevent the wire from moving freely. If the wire feed switch is turned on and the wire is not able to move freely through the tip, the wire will become twisted inside the welder. Use a suitable tool, such as a file, to remove spatter from the tip and then check to see that the wire comes out smoothly.

- Contact tip conditions. To ensure a stable arc, the tip should be replaced if it has become worn. For a good current flow and stable arc, keep the tip properly tightened (Figure 7-37).

**HEAT BUILD-UP PREVENTION**

Too much heat during welding distorts and weakens the metal. Always make sure you do not allow excess heat to transfer into any area of a panel. Use stitch or skip welding methods described earlier.
Stitch and skip welding will prevent costly and time consuming panel warpage. Another method of preventing heat build-up is heat sink compound. Heat sink compound is a paste that can be applied to parts to absorb heat and prevent warpage. It comes in a can and can be applied and reused. The heat sink compound is sticky and can be placed on the panel next to the weld. Heat will flow into the compound and out of the metal to prevent heat damage.

Heat crayons or thermal paint can also be used to warn you when a panel is becoming too hot. They are commonly used on aluminum, which does not change color with heat and will be discussed later.

**CLAMPING TOOLS FOR WELDING**

Locking jaw (vise) pliers, C-clamps, sheet metal screws, tack welds, or special clamps, described in Chapter 3, are necessary tools for good welding practices. Anybody can clamp panels together (Figure 7-38), but clamping panels together correctly to guarantee a sound weld will require close attention to every detail. As shown in Figure 7-39, a hammer and dolly can often be used to fit panels closely together in places that cannot be clamped.

Many times clamping both sides of a panel is not possible. In these cases, sheet metal screws or pop rivets can be employed to gain proper clamping during welding operations. To clamp panels together with sheet metal screws, punch or drill holes through the panel. In the case of plug welding, every other hole is filled with a sheet metal screw. The empty holes are then plug welded using proper plug welding techniques. After the original holes are plug welded, the sheet metal screws are removed and the holes left from the sheet metal screws are then plug welded.

Fixtures can also be used in some cases to hold panels to be welded in proper alignment. Fixtures alone, however, should not be depended upon to maintain tight clamping force at the welded joint. Some additional clamping will be required to make sure that panels are tightly clamped together and not just held in proper alignment.

**WELDING POSITION**

In collision repair, the welding position is usually dictated by the location of the weld in the structure of the car. Both the heat and wire speed parameters can be affected by the welding position (Figure 7-40).

Flat welding means the pieces are parallel with the bench or shop floor. Flat welding is generally easier and faster and allows for the best penetration (Figure 7-41). When welding a member that is off
the car, try to place it so that it can be welded in the flat position.

**Horizontal welding** has the pieces turned sideways. Gravity tends to pull the puddle into the bottom piece. When welding a horizontal joint (Figure 7-42), angle the gun upward to hold the weld puddle in place against the pull of gravity.

**Vertical welding** has the pieces turned upright. Gravity tends to pull the puddle down the joint. When welding a vertical joint (Figure 7-43), the best procedure is usually to start the arc at the top of the joint and pull downward with a steady drag.

**Overhead welding** has the workpieces turned upside down. Overhead welding is the most difficult. In this position (Figure 7-44), the danger of having too large a puddle is obvious; some of the molten metal can fall down into the nozzle, where it can create problems. So always do overhead welding at a lower voltage, while keeping the arc as short as possible and the weld puddle as small as possible. Press the nozzle against the work to ensure that wire is not moved away from the puddle. It is best to pull the gun along the joint with a steady drag.

**7.4 BASIC WELDING TECHNIQUES**

As shown in Figure 7-45, there are six basic welding techniques employed with MIG equipment.

- **Tack weld.** The tack weld is exactly that: a tack—a relatively small, temporary MIG spot weld that is used instead of a clamp or sheet metal screw to tack and hold the fit in place while proceeding to make a permanent weld. And like the clamp or sheet metal screw, a tack weld is always a temporary device. The distance between each tack weld is determined by the thickness of the panel. Ordinarily, a length of 15 to 30 times the thickness of the panel is appropriate (Figure 7-46). Temporary welds are very important in maintaining proper panel alignment and must be done accurately.

- **Continuous weld.** In a continuous weld, an uninterrupted seam or bead is laid down in a slow, steady, ongoing movement. Support the gun securely so it does not wobble. Use the forward method, moving the torch continuously at a constant speed, looking frequently at the welding bead. The gun should be inclined between 10 and 15 degrees to obtain the best bead shape, welding line, and shield effect (Figure 7-47). Maintain proper tip-to-base metal distance and correct gun angle. If the weld is not progressing well, the problem might be that the wire length is too long. If this is the case, penetration of the metal will not be adequate. For proper penetration and a better weld, bring the gun closer to the base metal. If the gun handling is smooth and even, the bead will be of consistent height and width, with a uniform, closely spaced ripple.


**Figure 7-45** Memorize the basic welding techniques.

**Figure 7-46** Temporary or tack welding is commonly used to hold parts in place before the final continuous weld. (Courtesy of Toyota Motor Corp.)

- **Plug weld.** A plug weld is made in a drilled or punched hole through the outside piece (or pieces). The arc is directed through the hole to penetrate the inside piece. The hole is then filled with molten metal.
- **Spot weld.** In an MIG spot weld, the arc is directed to penetrate both pieces of metal, while triggering a timed impulse of wire feed.
- **Lap spot weld.** In the MIG lap spot technique, the arc is directed to penetrate the bottom piece and the puddle is allowed to flow into the edge of the top piece.
- **Stitch weld.** A stitch weld is a series of connecting or overlapping MIG spot welds, creating a continuous seam.

**Basic Welding Methods**

Each type of joint can be welded by several different techniques. The technique used depends mainly on the given welding situation:

1. The thickness or thinness of the metal
2. The condition of the metal
3. The amount of gap, if any, between the pieces to be welded
4. The welding position

For example, the butt joint can be welded with the continuous technique or the stitch technique. And it can be tack welded at various points along the
joint to hold the parts in place while completing the joint with a permanent continuous weld or a stitch weld. Lap and flange joints can be made using all six welding techniques.

**Making Butt Welds**

Butt welds are formed by fitting two edges of adjacent panels together and welding along the mating or butting edges of the panels.

In butt welding, especially on thin panels, it is wise not to weld more than 3/4 inch (19 mm) at one time. Closely watch the melting of the panel, welding wire, and the continuity of the bead. Be sure the end of the wire does not wander away from the butted portion of the panels. If the weld is to be long, it is a good idea to tack weld the panels in several locations (stitch weld) to prevent panel warpage (Figure 7-48). Figure 7-49 shows how to generate an arc a short distance ahead of the point where the weld ends and then immediately move the gun to the point where the bead should begin. The bead width and height should be uniform at this time.

Weld in a sequence that allows an area to cool before the next area is welded (Figure 7-50). To fill the spaces between intermittently placed beads, first grind the beads along the surface of the panel. Then fill the space with metal (Figure 7-51). If weld metal is placed without grinding the surface of the beads, blowholes can be produced.

When welding thin panels that are 1/32 inch (0.79 mm) or less, an intermittent or stitch welding technique is a must to prevent burn-through. The combination of the proper gun angle and correct cycling techniques will enable you to achieve a satisfactory weld bead (Figure 7-52). The reverse welding method (Figure 7-29) can be used for moving the gun because it is easier to aim at the bead.

Figure 7-53 shows a typical butt welding procedure for installing a replacement panel. If the desired results are not obtained, the cause can be that the distance between the tip of the gun and the base metal might be too great. Weld penetration decreases

**FIGURE 7-49** If gun handling is smooth and even, the bead will be of a consistent height and width, with a uniform, closely spaced ripple.

**FIGURE 7-50** Compare the right and wrong welding sequence. [Courtesy of Nissan Motor Corp.]

**GOOD**

```
1 2 3 4 5 6 7
Less strain will be caused if welded section by section.
```

**WRONG**

```
1 2 3 4 5 6 7
Much strain will be caused if welded continuously.
```

Grind surface of beads.

**FIGURE 7-51** Filling the space between intermittently spaced beads will finish this weld.

**SECTION A-A**

**FIGURE 7-48** Tack weld of panels will also help prevent warpage. [Courtesy of Nissan Motor Corp.]
Aim at the end of the bead.  
Aim near the center of the bead.

**FLAT**  
**BEAD SHAPE**  
**BUILT-UP**

**RHYTHM**  
**AIMING POSITION**

**BZZ. BZZ. BZZ. BZZ**

Without waiting for the bead to cool, jump to the next position immediately.

**FLAT**  
**BEAD SHAPE**  
**BUILT-UP**

**DEEP**  
**PENETRATION**  
**SHALLOW**

**ARC OFF TIME FLUCTUATION**

**BZZZZ. BZZZZ. BZZZZ**

The puddle and bead diameter will increase when the gun is held in the same position for a long time.

**FLAT**  
**BEAD SHAPE**  
**BUILT-UP**

**DEEP**  
**PENETRATION**  
**SHALLOW**

**ARC ON TIME FLUCTUATION**

**BZ. BZ. BZ. BZ**

The puddle and bead diameter will decrease when the gun is held in the same position for a shorter period of time.

**FIGURE 7-52** Study the steps in achieving a proper bead. (Courtesy of Toyota Motor Corp.)
Align the body lines and tack weld the panel in several locations.

Match up the level differences in the panel surfaces and tack weld the panel in place.

Do NOT weld continuously from one point to another. Use an interrupted (stitch type) weld.

**FIGURE 7-53** Note the procedure for butt welding sectional areas. *(Courtesy of Toyota Motor Corp.)*

**INCORRECT**

Insufficient penetration. Weld strength is poor and the panel could separate when the panel is finished with a grinder.

**INCORRECT**

There is good penetration but finish grinding will be both difficult and time consuming.

**CORRECT**

Good Penetration and Easy to Grind

**FIGURE 7-54** Compare bead cutaway shapes.

**CORRECT**

**TOO FAST**

**TOO SLOW**

**FIGURE 7-55** Gun movement speed affects the bead shape.
as the distance between the tip and the base metal increases. Try holding the tip of the gun at several distances away from the base metal until the proper distance gives the desired results (Figure 7-54).

Moving the gun too fast or too slowly (Figure 7-55) will give poor welding results (even if speed of wire feed is constant). A gun speed that is too slow will cause melt-through. Conversely, a gun speed that is too fast will cause shallow penetration and poor weld strength.

Even if a proper bead is formed during butt welding, panel warpage can result if the weld is started at or near the edge of the metal (Figure 7-56A). Therefore, to prevent warpage, disperse the heat into the base metal by starting the weld in the center of the panel. Frequently change the location of the weld area (Figure 7-56B). The thinner the panel thickness, the shorter the bead length.

When welding a butt joint, be sure the weld penetrates all the way through to the backside of the joint. Where the metal thickness at a butt joint is \( \frac{1}{16} \) inch (1.59 mm) or more, a gap should be left to assure full penetration. If it is not practical to leave a gap, grind a V-groove in the joint (Figure 7-57) so the weld can penetrate to the backside.

MIG butt welds are often used to make two joints when sectioning frame rails, rocker panels, and door pillars. For butt welds keep a gap between the two
pieces the thickness of one piece. This helps weld penetration and prevents expansion and contraction problems. Also, hold the gun at 90 degrees to the joint.

An insert, or backing strip, made of the same metal as the base metal can be placed behind the weld. The backing helps proper fit, helps align the joint, and gives the joint the same strength and rigidity as the original structure.

Making Lap and Flange Welds

Lap and flange welds (Figure 7-58) are made with identical techniques. They are formed by welding or fusing two surfaces to be joined at the edge of the top one of two overlapping surfaces. This is similar to butt welds except only the top surface has an edge. Lap and flange welds should be made only in repairs where they replace original factory lap or flange welds, or where outer panels and not structural panels are involved. These welds should not be used to join more than two thicknesses of material together.

The same technique used for temperature control in butt welding should be followed for lap and flange welding. Welds should never be made continuously but should be sequenced to allow for natural cooling and to prevent temperature buildup in the welding area.

Making Plug Welds

The plug weld is the body shop alternative to the OEM resistance spot welds made at the factory because it can be used anywhere in the body structure that the factory used a resistance spot weld. Its use is not restricted. It has ample strength for welding load bearing structural members. It can also be used on cosmetic body skins and other thin-gauge sheet metal.

Plug welding (Figure 7-59) is a form of spot welding—spot welding through a hole. A plug weld is formed by drilling or punching (Figure 7-60) a hole in the outer panel being joined (Figure 7-61). The materials should be tightly clamped together. Holding the torch at right angles to the surface (Figure 7-62), aim the electrode wire in the hole, and trigger the arc while moving the gun in a circular motion around the hole (Figure 7-63). The puddle fills the hole and solidifies.

When plug welding, try to duplicate the number and the nugget size of the original factory spot welds. The hole that is punched or drilled should not be larger in diameter than the factory weld nugget. Drill or punch 1/16- to 3/8-inch (5-9mm) holes in top piece or pieces.

Start around the edge of the hole; then fill in the hole. A 5/16-inch (8 mm) hole works well for most
collision repair. A $\frac{3}{16}$-inch (5 mm) hole is better with very thin metals (24 gauge and lighter), and a $\frac{3}{8}$-inch (9 mm) hole is better with heavier metal (14 gauge and heavier).

When plug welds are used to join three or more panels together, holes are punched or drilled in every piece except the bottom piece. The holes are made progressively smaller from the top down. This is done to get better fusion of each layer to the adjacent one.

Typical hole size combinations are as follows. With three layers of metal, use $\frac{3}{16}$-inch (8 mm) and $\frac{3}{8}$-inch (9 mm) holes. With four layers, use $\frac{1}{4}$-inch (6 mm), $\frac{5}{16}$-inch (8 mm) and $\frac{1}{8}$-inch (9 mm) diameter holes.

Where MIG plug welds are used to replace factory spot welds:

1. Follow manufacturer's recommendations for number, size, and location of plug welds.
2. If this information is not available, duplicate the number, size, and location of original factory welds.

**FIGURE 7-62** The technician is making a plug weld while installing the panel.

Move it slowly. Aim at the center of the hole.

**FIGURE 7-63** The gun movement is circular to fill the plug weld.

**FIGURE 7-64** Remove oxide film with a wire brush or grinder.

Intermittent welding leads to the generation of oxide film on the surface and this causes blowholes. If this occurs, remove the oxide film with a wire brush (Figure 7-64).

Proper welding wire length is an important factor in obtaining a good plug weld. If the length of the wire protruding out of the end of the gun is too long, the wire will not melt properly, causing inferior weld penetration. The weld will improve if the gun is held closer to the base metal. Be sure the weld penetrates into the lower panel. Round dome-shaped protrusions on the underside of the metal are good indicators of proper weld penetration.

The area welded should be allowed to cool naturally before any adjacent welds are made. Areas around the weld should not be force cooled using water or air. It is important that they be allowed to cool naturally. Slow, natural cooling without using water or air will minimize any panel distortion and keep the strength designed into the panels.

Plug welds can also be used to join more than two panels together. A hole is punched in every panel except the lower panel (Figure 7-65). The diameter of the plug weld hole in each panel being joined should be smaller than the diameter of the plug weld hole on top. Likewise, if panels of different thicknesses are being joined, a larger hole is punched in the thinner panel to assure that the thicker panel is melted into the weld first. When welding panels of
Considerations important to high-quality plug welds are proper weld time, current flow, temperature, adjustments, clamping pressure, and filler rod type.

different thicknesses using the plug weld method, the thinner panel should be on top.

A plug weld using an MIG welder can be accomplished in a minimum amount of time, creating less temperature buildup in adjacent panels. While adjacent welds should not be made immediately, the area being welded will cool in a very short period of time.

Making Spot Welds

Most MIG machines that are designed for collision repair work have built-in timers that shut off the wire feed and welding arc after the time required to weld one spot (Figures 7-66 and 7-67). Some MIG equipment also has a burnback time setting. It can be adjusted to prevent the wire from sticking in the puddle. The setting of these timers depends on the thickness of the workpiece. This information can usually be found in the machine's owner's manual.

For MIG spot welding, a special welding nozzle (Figure 7-68) must replace the standard nozzle. Once in place and with the spot timing, welding heat, and backburn time set for the given situation, the spot nozzle is held against the weld site and the gun triggered. For a very brief period of time, the timed pulses of wire feed and welding current are activated, during which the arc melts the outer layer and penetrates the inner layer (Figure 7-69). After this, the automatic shutoff goes into action and no matter how long the trigger is squeezed, nothing will happen. The trigger must be released and then squeezed again to obtain the next spot pulse.

Because of varying conditions, the quality of an MIG spot weld is difficult to determine. On load bearing members, therefore, MIG plug welding is the preferred method.

The MIG lap spot technique is a popular one for the quick, effective welding of lap joints and flanges on thin-gauge nonstructural sheets and skins (Figure 7-70). Here again the spot timer is set, but this time the spot nozzle is positioned over the edge of the outer sheet at an angle slightly off 90 degrees. This will allow contact with both pieces of metal at the same time. The arc melts into the edge and penetrates the lower sheet.
Making Stitch Welds

In MIG stitch welding, the standard nozzle is used, not the spot nozzle. To make a stitch weld, combine spot welding with the continuous welding technique (Figure 7-71). To do this, set the automatic timer—either a shutoff or pulsed interval timer—depending on the MIG machine (Figure 7-72). The spot weld pulses and shutoffs occur with automatic regularity: weld-stop-weld-stop-weld-stop as long as the trigger is held in.

The arc-off period allows the last spot to cool slightly and start to solidify before the next spot is deposited. This intermittent technique means less distortion and less melt-through or burn-through. These characteristics make the stitch weld preferable to the continuous weld for working thinner-gauge cosmetic panels.

The intermittent cooling and solidifying of the stitch weld also makes it preferable to continuous welding on vertical joints where distortion is a problem (Figure 7-73). The welder does not have to contend with a continuous weld puddle that gravity is trying to pull down the joint ahead of the arc. Stitch welding is also preferable in the overhead position.

**Figure 7-69** During one brief, timed pulse of wire feed and welding current, the arc melts through the outer layer and penetrates the inner layer.

**Figure 7-70** The lap spot technique is a popular one for quick, effective welding of lap joints and flanges on thin-gauge nonstructural sheets and skins.

**Figure 7-71** Results of combining the spot welding process with continuous welding gun technique.

**Figure 7-72** The technician is setting the spot-off, or interval, timer.

**Figure 7-73** Intermittent cooling and solidifying of a stitch weld makes it preferable to continuous welding on vertical joints where distortion is a problem.
FIGURE 7-74 Stitch welding is also common in the overhead position.

FIGURE 7-75 A hand triggering welding gun will help control the heat on difficult welds.

With galvanized or zinc-coated steels (Figure 7-76), use a slower gun travel speed than when welding uncoated steels. This is because the zinc vapors tend to rise into the arc zone and interfere with arc stability. A slower travel speed allows the zinc to burn off at the front of the weld pool. How much to reduce the gun travel speed will depend on the thickness of the zinc coating, the joint type, and the welding position. Experience is the best teacher with these variable conditions.

Since there is slightly less weld penetration with galvanized or zinc-coated steels than with uncoated steels, a slightly under gap in square edge butt welds is needed. To prevent burn-through or excessive penetration of the wider gap, the welding gun should be handled with a side-to-side weaving motion.

It must be remembered that there is more spatter when welding galvanized or zinc-coated steels than with uncoated steels. Therefore, it is a good idea to apply antispatter compound inside the gun nozzle and to clean the nozzle frequently.

FIGURE 7-76 When welding galvanized or zinc-coated steels, use a slower gun travel speed.

7.5 MIG WELDING GALVANIZED METALS AND ALUMINUM

When MIG welding galvanized or zinc-metallized steels, also called zinc-coated steels, do not remove the zinc. If zinc is ground away, the thickness of the metal is reduced and so is its strength. And when a zinc-free area around the weld site is created, it is an inviting target for corrosion.

Always wear a welding respirator when fusing galvanized metals. The fumes can cause serious lung or respirator illness.

WELDING ALUMINUM

Several vehicles now have body, frame, and chassis parts made of aluminum. Whole bodies made of
than for steel. Make a practice weld on scrap pieces.

6. Position the two pieces together and lay a bead along the entire joint. The distance between the contact tip and the weld should be $\frac{5}{16}$ to $\frac{9}{16}$ inch (8 to 14 mm).

7. If the arc is too large, turn down the voltage and increase the wire speed. The bead should be uniform on top, with even penetration on the backside.

The high heat conduction of aluminum means that the technician must protect against warpage. There are two methods for doing this: stitch welding and center out welding, which were explained earlier.

Parts made of aluminum are usually $1\frac{1}{2}$ to 2 times as thick as steel parts. When damaged, aluminum feels harder or stiffer to the touch because of work hardening.

### 7.6 TESTING THE MIG WELD

Repair welds should be tested from time to time on every job. This can be done simply with test panels. Before welding on a vehicle, make some welds on pieces of scrap sheet metal like the panels that are going to be installed on the vehicle. If the proper settings on the MIG welder are obtained on the test pieces, the quality of the weld on the car can be assured. To check the quality of the weld, try to break it apart as illustrated in Figure 7-77.

### 7.7 MIG WELD DEFECTS

Defects in MIG welds and their causes are summarized in Table 7-5. Proper welding techniques assure good welding results. If welding defects should occur, think of ways to change your procedures to correct the defect.

When making any MIG repairs, the materials and panels must be similar enough to allow mixing when they are welded together. The melting and flowing of metals can be accomplished by many methods, depending upon the materials being joined. The combinations of cleanliness of the welded area, the mixing of proper metals, and the right heat application will result in a good MIG weld.

A welding problem causes a weak or cosmetically poor joint that reduces quality. Some common weld problems include:

1. **Weld Porosity** (holes in the weld)
2. **Weld Cracks** (cracks on the top or inside the weld bead)
3. **Weld Distortion** (uneven weld bead)

### 7.8 FLUX-CORED ARC WELDING

Flux-cored arc welding (FCAW) is an electric arc welding process that uses a tubular wire with flux inside. With the development of 0.030 self-shielded flux-cored wire, the flux-cored welding process has proven to be valuable for work on high-strength steel (coated or uncoated). The FCAW process uses the same type of constant potential power source as MIG. It also uses the electrode feed system, contact tube, electrode conduit, welding gun, and many other pieces of equipment that are used in MIG. Nevertheless, the process itself differs somewhat from MIG.

There is no external shielding gas in FCAW. As the flux within the wire melts in the heat of the arc, the created gases shield the weld puddle, stabilize the arc, help control penetration, and reduce porosity. The melted flux also mixes with the impurities on the metal surface and brings them to the top of the weld where they solidify as slag. The slag can then be chipped or brushed away.
## TABLE 7-5: WELDING PRECAUTIONS

<table>
<thead>
<tr>
<th>Defect</th>
<th>Defect Condition</th>
<th>Remarks</th>
<th>Main Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pores/Pits</td>
<td>![Pit Pore Diagram]</td>
<td>There is a hole made when gas is trapped in the weld metal.</td>
<td>1. There is rust or dirt on the base metal.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. There is rust or moisture adhering to the wire.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Improper shielding action (the nozzle is blocked or wind or the gas flow volume is low).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Weld is cooling off too fast.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5. Arc length is too long.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6. Wrong wire is elected.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7. Gas is sealed improperly.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8. Weld joint surface is not clean.</td>
</tr>
<tr>
<td>Undercut</td>
<td>![Undercut Diagram]</td>
<td>Undercut is a condition where the overmelted base metal has made grooves or an indentation. The base metal's section is made smaller and, therefore, the weld zone's strength is severely lowered.</td>
<td>1. Arc length is too long.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Gun angle is improper.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Welding speed is too fast.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Current is too large.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5. Torch feed is too fast.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6. Torch angle is tilted.</td>
</tr>
<tr>
<td>Improper Fusion</td>
<td>![Improper Fusion Diagram]</td>
<td>This is an unfused condition between weld metal and base metal or between deposited metals.</td>
<td>1. Check torch feed operation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Is voltage lowered?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Weld area is not clean.</td>
</tr>
<tr>
<td>Overlap</td>
<td>![Overlap Diagram]</td>
<td>Overlap is apt to occur in fillet weld rather than in butt weld. Overlap causes stress concentration and results in premature corrosion.</td>
<td>1. Welding speed is too slow.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Arc length is too short.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Torch feed is too slow.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Current is too low.</td>
</tr>
<tr>
<td>Insufficient Penetration</td>
<td>![Insufficient Penetration Diagram]</td>
<td>This is a condition in which there is insufficient deposition made under the panel.</td>
<td>1. Welding current is too low.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Arch length is too long.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. The end of the wire is not aligned with the butted portion of the panels.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Groove face is too small.</td>
</tr>
<tr>
<td>Excess Weld Spatter</td>
<td>![Excess Weld Spatter Diagram]</td>
<td>Excess weld spatter occurs as speckles and bumps along either side of the weld bead.</td>
<td>1. Arc length is too long.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Rust is on the base metal.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Gun angle is too severe.</td>
</tr>
<tr>
<td>Spatter (short throat)</td>
<td>![Spatter Diagram]</td>
<td>Spatter is prone to occur in fillet welds.</td>
<td>1. Current is too great.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Wrong wire is selected.</td>
</tr>
</tbody>
</table>
Two very important advantages of the FCAW process over MIG are its ability to tolerate surface impurities (thus requiring less precleaning) and to stabilize the arc. Other beneficial characteristics of the process include the following:

- High deposition rate.
- Efficient electrode metal use.
- Requires little edge preparation.
- Welds in any position.
- Welds a wide range of metal thicknesses with one size of electrode.
- Produces high-quality welds.
- Weld puddle is easily controlled and its surface appearance is smooth and uniform even with minimal operator skill.
- Produces a weld with less porosity than MIG when welding galvanized steels.

While the FCAW process has a number of advantages over MIG, it has the following drawbacks:

- FCAW wires are more expensive than MIG hard wires. However, the cost is quickly recovered through higher productivity.
- The flux from the wire changes to slag as it cools. Until it does cool, the slag is sharp and hot and should be considered an eye and skin hazard. Once it cools, this slag must be removed prior to the application of fillers, seam sealers, primers, or paint.
- Spatter is worse when using flux-cored wires. Use nozzle gel and keep the nozzle scraped clean. Spatter buildup in the gun nozzle can jam the wire in the contact tip; it can also fall off during welding and mix with the molten puddle, diminishing the quality of the weld.
- Excessive tension on the drive rollers or using the incorrect style of drive rollers can collapse the tubular wire. Check the owner’s manual for flux-cored wire requirements.
- Only ferrous metals can be welded.

If a machine is used for both MIG and FCAW, the welder must have polarity switching capabilities. FCAW with .030- or .035-inch (0.58, 0.76, or 0.89 mm) wire uses straight polarity while .023-, .030-, and .035-inch (0.58, 0.76, or 0.89 mm) hard wires for MIG use DC reverse polarity. Many of the gas metal arc welding machines sold over the past few years were originally designed to run DC reverse. Without going inside the machine to change polarities, which is difficult and time consuming, this type of machine will not run DC straight polarity. Check the owner’s manual for polarity reversing capabilities.

1. FCAW wires are more expensive per pound than hard wires for GMAW.
2. The .030-inch (0.58 mm) self-shielded cored wire contains fluoride compounds. **Use adequate ventilation.**
3. The flux in the core of the wire changes to slag upon cooling. This slag must be removed prior to the application of fillers, seam sealers, primers, or paint.
4. In addition, the slag is sharp and hot until it cools, so it must be considered an eye and skin hazard.
5. Spatter is worse when using cored wires. Use nozzle gel and keep the nozzle scraped clean. Spatter buildup in the gun nozzle can jam the wire in the contact tip or fall off during welding, mixing with the molten puddle and contributing to a poor quality weld.

6. Wire feed problems for FCAW are similar to those encountered with GMAW, but with one important difference. Because cored wires are not solid, excessive tension on the drive rolls or the incorrect style of drive rolls may collapse the tubular wire which leads to feeding problems. Again, check with the owner's manual for correct drive rolls and tension requirements for flux-cored wire.

7.9 TIG WELDING

Tungsten inert gas (TIG) welding, another form of GMAW, uses a nozzle-fed shielding gas and a hand-held filler rod. It has somewhat limited use in body shop repair applications. In a general auto repair or engine rebuilding, however, it does things that make it a valuable tool.

MIG welders lay down weld beads at the average of 25 inches (635 mm) per minute. TIG welding is much slower, with weld speeds ranging between 5 and 10 inches (127 to 254 mm) per minute. However, this slower speed gives much more control, and the end result is the best-looking weld obtainable. A TIG unit can be used to repair cracks in aluminum cylinder heads and reconstruct combustion chambers and other automotive components that need to be welded.

Like MIG (Figure 7–78), TIG welders use an inert gas, such as argon or helium, to surround the weld area and prevent oxygen and nitrogen in the atmosphere from contaminating the weld. But instead of having a wire feed welding electrode like MIG units, TIG machines use a tungsten electrode with a very high melting point (about 6,900 degrees Fahrenheit) to strike an arc between the welding gun and the work.

Since the tungsten electrode has such a high melting point, it is not consumed during the welding process. A filler rod must be used for welding thicker materials (Figure 7–79).

7.10 RESISTANCE SPOT WELDING

Resistance spot welding is the most important welding process used by automobile manufacturers. It is used on their assembly lines to make many of the OEM welds on unibody cars (Figure 7–80). It is estimated that between 90 to 95 percent of all factory welds in a unibody structure are spot welds. In this country, it is also widely used in the automotive aftermarket for sunroof installations and vehicle conversions, including recreational vehicles (RVs) and stretch limousines.

Since resistance spot welding is now specified by a growing number of automobile manufacturers for repair welding their vehicles, the repair specialist must know how to use a resistance spot welding gun.

The squeeze-type resistance spot welder (Figure 7–81) is ideal for repair welding many of the unibody's thin-gauge sections that require good weld strength and no distortion. Typical applications include roofs, window and door openings, rocker panels, and many exterior panels (Figure 7–82). Due to the strength requirements of unibody repairs, it is often important that a squeeze-type resistance spot welder be used and that the repair specialist know how to set it up, make test welds, and use it.

Resistance spot welding has several advantages:

- It reduces welding costs.
- No consumable filler wire, rod, or gas is required.
- It's clean with no smoke or fumes.
<table>
<thead>
<tr>
<th>Construction</th>
<th>Location</th>
<th>Construction</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspension mounting</td>
<td>G</td>
<td>Belt anchor</td>
<td>E</td>
</tr>
<tr>
<td>Steering gear mounting</td>
<td>H</td>
<td>Jack-up point</td>
<td>C, D</td>
</tr>
<tr>
<td>Fuel tank mounting</td>
<td>N</td>
<td>Major construction portions</td>
<td>A, I, J, K, L, M</td>
</tr>
<tr>
<td>Engine, transmission mounting</td>
<td>F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 7-80** This illustration gives important locations on the body for production spot welding. Refer to a specific service manual for the vehicle being repaired. *(Courtesy of Nissan Motor Corp.)*
It allows use of weld through conductive zinc primers to restore corrosion protection to repair joints.
- It duplicates OEM factory weld appearance.
- It eliminates need for grinding of welds.
- It’s fast; weld times of one second or less make strong welds on HSS and HSLA steels as well as mild steels with a very small heated zone, eliminating distortion of metal.

**HOW RESISTANCE SPOT WELDING WORKS**

_Resistance spot welding_ relies on the resistance heat generated by low-voltage electric current flowing through two pieces of metal held together, under pressure, by the squeeze force of the welding electrodes. Thus, the three important factors in the operation of resistance spot welding are

- **Pressurization.** The mechanical welding bond between two pieces of sheet metal is directly related to the amount of force exerted on the sheet metal by the welding tips. As the tips squeeze the sheet metal together, an electrical current flows from the tips through the base metal causing the metal to melt and fuse together. Weld spatter (internal or external) is the result of low pressure on the tip or excessive electrical current flow. A high tip pressure causes a small spot weld (Figure 7-83) and a reduced mechanical bond of the weld. In other words, the high tip pressure forces the tip into the softened area, thinning and weakening the weld.

- **Current flow.** When pressure is applied to the metal, a high electric current flows through the electrodes and through the two pieces of metal. The temperature rises rapidly at the joined portion of the metal where the resistance is greatest (Figure 7-84A). If the current continues to flow, the metal melts and fuses together (Figure 7-84B). If the electrical current becomes too great or the pressure too low, internal spatter will result. However, if the current is decreased or the pressure is increased, weld spatter will be held

**FIGURE 7-81** This is a squeeze-type resistance spot welder. (Courtesy of Lars Machinery, Inc.)

**FIGURE 7-82** Note the typical applications of a squeeze-type resistance spot welder: (A) welding the side quarter window pinch weld flange; (B) welding the right quarter panel to the rear side mainbar, trunk floor pan, and lower pack panel; and (C) welding the left rear quarter panel to the rear valance. (Courtesy of Lars Machinery, Inc.)

**FIGURE 7-83** Electrode (tip) pressure affects the spot weld.

---

**Great Pressurization Force**

- Small Nugget

**Small Pressurization Force**

- Large Nugget
Heat is generated from the resistance of the metal.

Metal is fused by the heat generated.

Pressurization to a minimum. As can be seen, there is a mutual relationship between the electrical current and the pressure applied to the spot weld.

- **Holding.** If the current flow is stopped, the melted portion begins to cool and forms a round flat bead of solidified metal (nugget) (Figure 7-85). This structure becomes very dense due to the pressurization force, and its subsequent mechanical bonding is excellent. Pressurization time is very important. Do not use less time than specified in the operator's manual.

**RESISTANCE SPOT WELDING COMPONENTS**

The components of a resistance spot welder (Figure 7-86) are the welding transformer, the welder control, and the welding gun with interchangeable arm sets.

The transformer converts low-amperage, 240-volt shop line current to high secondary amperage, low-voltage (2 to 5 volts) welding current, safe from electrical shock. The welder transformer can either be built into the welding gun or mounted remotely and connected to the gun by means of cables.

A built-in transformer is electrically more efficient since there is little or no loss of welding current between the transformer and the gun. A remote transformer must be larger and draw more shop line current to compensate for power losses through the long cables connecting it to the gun.

**FIGURE 7-86** Study the components of a resistance spot welding system. (Courtesy of Toyota Motor Corp.)
Remember that this high weld current will decrease when long reach or wide gap arm sets are used. A high weld current output can be adjusted to a lower intensity by use of the welder control.

The welder control adjusts the transformer’s weld current output and permits precise adjustment of the weld time during which the welding current is switched on and allowed to flow through the metal being welded and then switched off. It is desirable to have a range of timing adjustment from approximately ¼ of a second to 1 second (10 to 60 cycles) for typical collision repair welding applications. A repeatable accuracy of at least ½ of a second is desirable for consistent weld quality.

The welder control should be capable of providing a full range of adjustment of the welding current. Weld current settings vary, depending upon the thickness of the steel to be welded and the length and gap of the arm sets needed to reach into the area being welded. It might be necessary to decrease weld current when welding with short reach arm sets, or increase weld current when using long reach or wide gap arm sets.

Some manufacturers of resistance spot welders designed for unibody repair work offer additional control features that compensate for small amounts of surface scale or slight rust on the metal. Such features permit the repair specialist to determine when a poor weld condition exists.

The welding gun applies the squeeze force and delivers the welding current through the welder arms to the metal being welded. Most resistance spot welders are designed with a force multiplying mechanism to produce the high electrode force required for consistent weld quality. These force multiplying mechanisms can be spring or pneumatically assisted. Squeeze-type resistance welders that do not use a force multiplying mechanism and rely solely on the operator’s manual grip for pressure are not recommended for repair welding unibody structures.

The majority of welding guns in auto body shops should have a maximum capacity of up to two times

\[
\frac{1}{4}\text{-inch-thick (1.98 mm) steel when equipped with short reach arm sets of 5 inches (127 mm) or less. Capacity with long reach or wide gap arm sets should be at least two times } \frac{1}{2}\text{-inch-thick (0.79 mm) steel. These capacities comply with the specifications listed in most factory body repair manuals.}
\]

Resistance spot welders used for unibody repair welding are available with a full range of interchangeable arm sets. Standard arm sets (Figure 7–87) are designed to reach difficult areas on most makes of cars, such as wheel well flanges, drip rails, taillight openings, and other tight pinch weld areas, as well as floor pan sections, rocker panels, and window and door openings. Repair shops doing work for new car dealers should check the factory repair manuals and look for availability of special arm sets for the hard-to-reach areas on specific makes of cars.

**SPOT WELDER ADJUSTMENTS**

To obtain sufficient strength at the spot-welded portions, perform the following checks and adjustments on the squeeze-type resistance spot welding gun before starting:

- **Arm selection.** It is important to select the arm according to the area to be welded (Figure 7–88).
- **Adjustment of arm.** Keep the gun arm as short as possible to obtain the maximum pressure for welding (Figure 7–89). Securely tighten the gun arm and tip so that they will not become loose during the operation.
- **Alignment of electrode tips.** Align the upper and lower electrode tips on the same axis (Figure 7–90). Poor alignment of the tips causes insufficient pressurizing, and this results in insufficient current density and insufficient strength at the welded portions.
- **Diameter of electrode tip.** The diameter of the spot weld decreases as the diameter of the electrode tip increases. Also, if the electrode tip is too small, the spot weld will not increase in size. The tip diameter (Figure 7–91) must be properly controlled to obtain the desired welding strength. Before starting operation, make sure that the tip diameter (D) is kept the proper size, and file it cleanly to remove burnt or foreign matter from the surface of the tip. As the amount of dirt on the tip increases, the resistance at the tip also increases, which reduces the current flow through the base metal that in turn reduces weld penetration resulting in an inferior weld. If the

![Figure 7–87 Various accessory arms are needed to reach around the panels to be welded. (Courtesy of Henning Hansen, Inc.)](image-url)
Figure 7-88 Select the proper type of arm for the job. (Courtesy of Toyota Motor Corp.)

Figure 7-89 Adjust gun arms for proper alignment. (Courtesy of Nissan Motor Corp.)

Figure 7-90 Study correct and incorrect alignment of electrode tips. (Courtesy of Nissan Motor Corp.)
tips are used continuously over a long period of time, they will not dissipate heat properly and will become red hot. This will result in premature tip wear that also increases resistance and causes the welding current to drop drastically. If necessary, let the tips cool down after five or six welds. If the tips are worn, use a tip dressing tool to reshape the tips (Figure 7-92).

- Electrical current flow time. Current flow time also has a relationship to the formation of a spot weld. When the electrical current flow time increases, the heat that is generated increases the spot weld diameter and penetration. The amount of heat that is dissipated at the weld increases as the current flow time increases. Since the weld temperature will not rise after a certain amount of time, even if the current flows longer than that time, the spot weld size will not increase. However, tip pressure marks and heat warping might occur.

The pressurization force and welding current of many spot welders cannot be adjusted and the current value might be low. However, welding strength can be assured by lengthening the current flow time (letting low current flow for a long time).

While spot welding galvanized or zinc-coated steel panels used in auto bodies, offset the drop in current density by raising the current value 10 to 20 percent above that for ordinary steel panels. Since the current value cannot be adjusted in spot welders ordinarily used for body repairs, lengthen the current flow time a little.

The best welding results can be obtained by adjusting the arm length or welding time according to the thickness of the panels. While the welder instruction manual has these values listed inside, it is best to test the quality of the weld using the methods described later.

**OPERATING A SQUEEZE-TYPE RESISTANCE SPOT WELDER**

Hold the welding gun and position it so that the welder arm electrodes contact the body parts to be welded. Then use the squeeze mechanism to apply weld force to both sides of the metal being welded. As force is applied and maintained on the metal, the force mechanism initiates an electrical signal to the welder control that switches on the flow of weld current for a preset time and then switches it off. Since the weld time is usually less than one second, the entire process is very fast.

Other important operational considerations when using a squeeze-type resistance spot welder are:

- Clearance between welding surfaces. Any clearance between the surfaces to be welded causes poor current flow (Figure 7-93). Even if welding can be made without removing such a gap, the welded area would become smaller, resulting in
insufficient strength. Flatten the two surfaces to remove the gap and clamp them tightly with a clamp before welding.

- **Metal surface to be welded.** Paint film, rust, dust, or any other contamination on the metal surfaces to be welded cause insufficient current flow and poor results. Remove such foreign matter from the surfaces to be welded (Figure 7-94).

- **Corrosion.** Coat the surfaces to be welded with an anticorrosion agent (see Chapter 16) that has higher conductivity. It is important to apply the agent uniformly even to the end face of the panel (Figure 7-95).

- **Performance of spot welding operations.** When performing spot welding operations, be sure to use the direct welding method. For the portions to which direct welding cannot be applied, use plug welding by MIG welding.

Apply electrodes at a right angle to the panel (Figure 7-96A). If the electrodes are not applied at right angles, the current density will be low, resulting in insufficient welding strength.

For the portion where three or more metal sheets are overlapping, spot welding should be done twice (Figure 7-96B).

- **Number of points of spot welding.** The capacity of spot welding machines available in a repair shop generally is smaller than that of welding machines at the factory. The number of points of spot welding should be increased accordingly by 30 percent in a service shop compared to spot welding in the factory (Figure 7-97).

- **Minimum welding pitch.** The strength of individual spot welds is determined by the **spot weld pitch** (the distance between spot welds) and **edge distance** (the distance of the spots from the panel edge). The bond between the panels becomes stronger as the weld pitch is shortened. However, over a certain point, the metal becomes saturated and further shortening of the pitch will not increase the strength of the bond because the current will flow to the spots that have previously been welded. This reactive current diversion increases as the number of spot welds increases, and the diverted current does not raise the temperature at the welds (Figure 7-98). The distance of the weld pitch must be beyond the area influenced by the reactive current diversion. In general, the values given in Table 7-6 should be observed.

- **Before Operation**
- **Apply agent to the whole surface including the end face.**

**Figure 7-95** Apply an anticorrosion agent to metal surfaces requiring protection from rust. The service manual will give locations of the areas needing an agent.

**Figure 7-96** Precautions in performing spot welds.

(A) Make sure tips are parallel and at right angles to the panels. (B) Spot weld twice for large total panel thickness.

**Figure 7-97** The number of points to spot weld will also be given in the vehicle’s service manual.
TABLE 7-6: SPOT WELDING POSITION

<table>
<thead>
<tr>
<th>Panel Thickness</th>
<th>Pitch S</th>
<th>Edge Distance P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/64&quot;</td>
<td>7/16&quot; or more</td>
<td>13/64&quot; or more</td>
</tr>
<tr>
<td>1/32&quot;</td>
<td>9/16&quot; or more</td>
<td>13/64&quot; or more</td>
</tr>
<tr>
<td>Less Than 3/64&quot;</td>
<td>11/16&quot; or more</td>
<td>1/4&quot; or more</td>
</tr>
<tr>
<td>3/64&quot;</td>
<td>7/8&quot; or more</td>
<td>9/32&quot; or more</td>
</tr>
<tr>
<td>1/16&quot;</td>
<td>1-9/64&quot; or more</td>
<td>5/16&quot; or more</td>
</tr>
</tbody>
</table>

**FIGURE 7-98** Minimum welding pitch is spec for how far apart the welds should be.

**WELDING SEQUENCE**

- **GOOD** 1 5 3 4 2
- **WRONG** 1 2 3 4 5

**FIGURE 7-99** Memorize the proper welding sequence. (Courtesy of Nissan Motor Corp.)

- **Position of welding spot from edge and end of panel.** The edge distance is also determined by the position of the welding tip. Even if the spot welds are normal, the welds will not have sufficient strength if the edge distance is insufficient. When welding near the end of a panel, observe the values for the distance from the end of a panel given in Table 7-7. If the distance is too small, it results in insufficient strength and also in a strained panel.

**FIGURE 7-100** Often, you do not weld corners; just weld right up to them or as directed in the manual. (Courtesy of Nissan Motor Corp.)

- **Spotting sequence.** Do not spot continuously in one direction only. This method provides weak welding due to the shunt effect of the current (Figure 7-99). If the welding tips become hot and change their color, stop welding and allow them to cool.
- **Welding corners.** Do not weld the corner radius portion (Figure 7-100). Welding this portion results in concentration of stress that leads to cracks. The following locations require special consideration:
  - Upper corner of front and center pillars
  - Front upper portion of the quarter panel
  - Corner portion of front and rear windows

**INSPECTION OF SPOT WELDS**

Spot welds are inspected either by outward appearance (visual inspection) or destructive testing. Destructive testing is used to measure the strength of a weld, and a visual inspection is used to judge the quality of the outward appearance.

**Appearance Inspection**

Check the finish of the weld visually and by touching. The items to check are:

- **Spot position.** The spot weld position should be in the center of the flange with no tip holes and...
have no spot welds overriding the edge. As a rule, an old spot position should be avoided.

- **Number of spots.** There should be 1.3 or more times the number made by the manufacturers. (For example, 1.3 times 4 original factory spot welds equals roughly 5 new repair spot welds.)
- **Pitch.** It should be a little shorter than that of the manufacturer and spots should be uniformly spaced. The minimum pitch should be at a distance where reactive current diversion will not occur.
- **Dents (tip bruises).** There should be no dents on the surfaces that exceed half the thickness of the panel.
- **Pinholes.** There should be no pinholes that are large enough to see.
- **Spatter.** A glove should not catch on the surface when rubbed across it.

<table>
<thead>
<tr>
<th>Thickness (t)</th>
<th>Minimum pitch (l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/64&quot;</td>
<td>7/16&quot; or over</td>
</tr>
<tr>
<td>1/32&quot;</td>
<td>7/16&quot; or over</td>
</tr>
<tr>
<td>Less than 3/64&quot;</td>
<td>15/32&quot; or over</td>
</tr>
<tr>
<td>3/64&quot;</td>
<td>9/16&quot; or over</td>
</tr>
<tr>
<td>1/16&quot;</td>
<td>5/8&quot; or over</td>
</tr>
<tr>
<td>5/64&quot;</td>
<td>11/16&quot; or over</td>
</tr>
</tbody>
</table>

### Destructive Testing

Most destructive tests require the use of sophisticated equipment, a requirement that most body shops are unable to meet. For this reason, simpler methods described here have been developed for general use in body shops.

- **Destructive test.** A test piece of the same metal as the welded piece and with the same panel thickness is made and welded in the positions shown in Figure 7-101. Force is then applied in the direction of the arrow and the spots are separated. It is then judged by how cleanly the weld has broken whether it is satisfactory or not. If the weld pulls out cleanly, like a cork from a bottle, the weld is judged to be good. It should be noted that since the weld performance cannot be exactly duplicated by this test, the results should only serve as a reference.

- **Nodestructive test.** To confirm a spot weld after it has been made, use a chisel and hammer and proceed as follows:

  Insert the tip of a chisel between the welded plates (Figure 7-102) and tap the end of the chisel until a clearance of 1/8 to 1/32 inches (3.2 to 3.97 mm) (when the plate thickness is approximately 1/32 inch (0.79 mm)) is formed between the plates. If the welded portions remain normal, it indicates that the welding has been done prop-
erly. This clearance varies with the location of the welded spots, length of the flange, plate thickness, welding pitch, and other factors. Note that the values given here are only reference values.

If the thickness of the plates is not equal, the clearance between the plates must be limited to \(\frac{1}{16}\) to \(\frac{3}{32}\) inches (1.58 to 1.98 mm). Note that further opening of the plates can become a destructive test.

Be sure to repair the deformed portion of the panel after inspection.

### 7.11 Other Spot Welding Functions

While the squeeze-type welding gun is the most used in the repair shop, there are other types of guns used with spot welding equipment. With the proper gun attachment, the spot welder can be used as a panel spotter, stud welder, spot shrinker, and mold rivet welder.

#### Panel Spotting

At one time spot welding equipment was called a panel spotter (Figure 7-103). When operating a panel spotter, the two electrode guns are placed on the nonstructural replacement panel. Figure 7-104 shows how both lap and flange joints can be made with a spliced panel or full panel installation.

After the adjustments are made following the manufacturer's directions, push both electrodes against the panel and apply moderate pressure to close any gaps. Press the weld button on the switch handle and hold it down until the welding cycle stops automatically. Release the weld button and move the electrodes to the next welding location.

Here are some other panel spotter operational tips:

- Thoroughly clean the surfaces along the weld seam. If a new replacement has been primed, strip off this coat on both sides of the panel and along the weld seam with a coarse abrasive paper. If the panel has a rust preventative film coating instead of a primer, merely wipe off both sides of the weld seam with a clean rag and solvent.

- Use vise grips on all flange joint and drip rail applications (Figure 7-105) to bring the parts closely together. Weld near the vise grip jaws where the fit-up is tight.

![Fig. 7-103](https://example.com/fig7103.png)

**Fig 7-103** This is a typical panel spotter. (Courtesy of Lenco Inc.)

![Fig. 7-104](https://example.com/fig7104.png)

**Fig 7-104** Note the method of panel spotting lap and flange joints.
• A few sheet metal screws can be used on lap joints to position the panel for spot welding. Make sure that the paint has been removed from the joints.
• On long splice jobs, start in the middle of the panel and spot weld in one direction. For example, go from the middle of the panel to the door post. Start again in the middle and complete the panel welds to the tail light area. This is an additional aid in eliminating distortion.
• Removal of burrs on the newly cut panel insures getting good metal-to-metal contact when body pressure is applied to the electrodes. Burrs and dents cause an air space between mating parts and prevent positive metal contact.

The twin electrodes of the panel spotter often permit spot welding in spaces where the squeeze-type has difficulty operating. In addition, the panel spotter can be converted to a squeeze-type spot welder.
with a gun attachment. However, this arrangement should be used only on nonstructural parts, never on structural parts.

7.12 STUD SPOT WELDING FOR DENT REMOVAL

Studs used in dent removal can be resistance welded with a special stud welder (Figure 7–106) or a panel spotter equipped with stud welding attachments (Figure 7–107). With either method, a stud pulling kit (Figure 7–108) containing all the necessary items (including a slide hammer) is a must for dent removal.

To remove a dent properly with either a stud or stud spot welder, a good quality stud is necessary. The stud should offer the necessary combination of pull strength and tensile strength, while remaining extremely flexible. The flexibility allows the stud to be bent out of the way when working on adjacent studs, then bent back when required. The importance of this stud is to minimize the heat required and, therefore, maintain the flexibility of the steel when being applied and removed. Complete details on using stud or panel welding for dent removal can be found in Chapter 8.

7.13 MOLD RIVET WELDING

Although many decorative strips are applied with adhesive, moldings are still applied with mold rivets and clips. For example, chrome strips on rocker pans and window and vinyl roof moldings are often held this way.

When patching or refinishing areas that are susceptible to moisture, salt, or high humidity, a technician is usually apprehensive about drilling holes exposing inner panels. Mold rivet welding with a stud or spot welder is a logical solution. As shown in Figure 7–109, one electrode has the mold rivet welding tip, while the other has the ground tip. No holes are made; rivets can be relocated or replaced without exposing vulnerable areas to outside elements. This one-step operation achieves a factory replica and is ideal for placing rivets on new skins. If rivets need to be removed or relocated, they require very little grinding.

7.14 OXYACETYLENE WELDING

Oxyacetylene welding is a type of fusion welding. Acetylene and oxygen are mixed in a chamber, ignited at the tip, and used as a high-temperature heat source (approximately 5,400 degrees Fahrenheit or 2,984 degrees Celsius) to melt and join the welding rod and base metal together (Figure 7–110).

Since it is difficult to concentrate the heat in one area, the heat affects the surrounding areas and reduces the strength of steel panels. Because of this problem, auto makers do not recommend the use of oxyacetylene in repairs of damaged vehicles. Although oxyacetylene is in disfavor with most automobile manufacturers—with good reason—it has some use in the body shop. The oxyacetylene flame is still used to repair other damaged auto bodies, and for some heat shrinking operations, brazing, soldering, surface cleaning, and cutting of nonstructural parts. Oxyacetylene should not be used to cut structural parts of any vehicle unless special care is taken.

**FIGURE 7-109** A panel spotter can also be used to install molding rivets. *(Courtesy of Lenco Inc.)*

**FIGURE 7-110** An oxyacetylene welder is seldom used to weld body panels because of the heat warpage that results.
WELDING AND CUTTING EQUIPMENT

In general, an oxyacetylene welding and cutting outfit (Figure 7-111) consists of the following:

- **Steel tanks (cylinders)** filled with
  - Oxygen
  - Acetylene

*FIGURE 7-112* It is important to be familiar with cutting torch adjustments.

- **Regulators**, which reduce the pressure coming from the tanks to the desired level and maintain a constant flow rate of
  - Oxygen pressure: 15 to 100 psi (103 to 689 kPa)
  - Acetylene: 3 to 12 psi (21 to 83 kPa)
- **Hoses** from the regulators and cylinders connect the oxygen and acetylene to the torch.
- **Torch.** The torch body mixes the oxygen and acetylene from the tanks in the proper proportions and produces a heating flame capable of melting steel. There are two main types of torches:
  - Welding torch
  - Cutting torch

The low-pressure torch is generally used for acetylene welding. This torch can be used at an extremely
To round out the equipment, the safety gear described in Chapter 1 should be worn. Welding should be done with either a number 4, 5, or 6 tinted filter shade. A spark lighter (Figure 7–114) is another necessity.

**TYPES OF FLAME AND ADJUSTMENT**

When acetylene and oxygen are mixed and burned in the air, the condition of the flame varies depending on the volume of oxygen and acetylene.

There are three forms of flame:

- **Neutral flame.** The standard flame is said to be a neutral flame. Acetylene and oxygen mixed in a 1 to 1 ratio by volume produces a neutral flame. As shown in Figure 7–115A, this flame has a brilliant white cone surrounded by a clear blue outer flame.

- **Carburizing flame.** The carburizing flame, also called a surplus or reduction flame, is obtained by mixing slightly more acetylene than oxygen. Figure 7–115B shows that this flame differs from the neutral flame in that it has three parts. The cone and the outer flames are the same as the neutral flame, but between them there is an intermediate light-colored acetylene cone enveloping the cone. The length of the acetylene cone varies according to the amount of surplus acetylene in the gas mixture. For a double surplus flame, the oxygen-acetylene mixing ratio is about 1 to 1.4 (by volume). A carburizing flame is used for welding aluminum, nickel, and other alloys.

- **Oxidizing flame.** The oxidizing flame is obtained by mixing slightly more oxygen than acetylene. The oxidizing flame (Figure 7–115C) resembles the neutral flame in appearance, but the acetylene cone is shorter and its color is a little more violet compared to the neutral flame. The outer flame is shorter and fuzzy at the end. Ordinarily, this flame oxidizes melted metal, so it is not used in the welding of mild steel, but it is used in the welding of brass and bronze.

---

**CAUTION**

The acetylene line pressure must never exceed 15 psi [103 kPa]. Free acetylene has a tendency to dissociate at pressure above 15 psi [103 kPa] and could cause an explosion.
WELDING TORCH FLAME ADJUSTMENT

As stated in the overview of welding, oxyacetylene welding is not used for welding modern auto bodies, but it is used for brazing certain nonstructural panels at factory-brazed seams. When using a welding torch, proceed as follows:

1. Attach the appropriate tip to the end of the torch. Use the standard tip for sheet metal (each torch manufacturer has a different system for measuring the size of the tip orifice).

2. Set the oxygen and acetylene regulators at the proper pressure:
   Oxygen = 8 to 25 psi (55 to 172 kPa)
   Acetylene = 3 to 8 psi (21 to 55 kPa)

3. Open the acetylene valve about half a turn and ignite the gas. Continue to open the valve until the black smoke disappears and a reddish yellow flame appears. Slowly open the oxygen valve until a blue flame with a yellowish white cone appears. Further open the oxygen valve until the center cone becomes sharp and well defined. This type of flame is called a neutral flame and is used for welding mild steel (other than automobile bodies).

If acetylene is added to the flame or oxygen is removed from the flame, a carburizing flame will result.

If oxygen is added to the flame or acetylene is removed from the flame, an oxidizing flame will result.

GAS CUTTING TORCH FLAME ADJUSTMENT

The cutting torch is sometimes used in collision repair shops to rough cut damaged panels. Gas cutting torch flame adjustment and cutting procedures are as follows:

1. Adjust the oxygen and acetylene valves for a preheating neutral flame.

2. Open the preheating oxygen valve slowly until an oxidizing flame appears. This makes it difficult for melted metal to remain on the surface of the cut panel, allowing for clean edges.

3. Thick panel cutting method. Heat a portion of the base metal until it is red hot. Just before it melts, open the high-pressure oxygen valve and cut the panel. Advance the torch forward while making sure the panel is melting and being cut apart. This method is widely used for thick panels when there are several pieces overlapped together or for a side member, even when there is an internal reinforcement.

4. Thin panel cutting method. Heat a small spot on the base metal until it is red hot. Just before it melts, open the high-pressure oxygen valve and incline the torch to cut the panel. When cutting thin material, incline the tip of the torch so that the cut will be clean and fast (this prevents unwanted panel warpage).

As soon as the cutting operation is completed, quickly turn off the high-pressure oxygen flow used for cutting and pull the torch away from the base metal. This action prevents sparks from entering the tip and igniting the oxygen-acetylene mixture in the torch handle. In extreme cases the ensuing fire could melt the torch handle.

CUTTING HSS FOR SALVAGE PURPOSES

Salvage components must be cut with a grinding wheel disc, an air chisel and/or metal cutting saw, or with a plasma cutter. If the use of a gas torch is necessary when cutting HSS sheet metal components for salvage purposes or cutting a body structure for a front/rear clip, factory engineers advise the following approach:

- Cut the metal structure at least 2 inches (51 mm) away from the desired cut line. Sheet metal within the heat-affected area will lose strength when subjected to the high heat levels of a torch.
- After torch cutting, use a grinding wheel disc, an air chisel, or a metal saw to make the final cut at the originally intended dimension line. HSS damage will then be cut out of the salvaged part.

FIGURE 7-116 Discoloration of HSS heat-affected steel will weaken the metal and cause distortion.
As stated previously, oxyacetylene equipment should not be used on HSS components for welding or cutting. Vehicle manufacturer's engineers stress this point. There is just too much heat buildup that can reduce structural strength. However, in some instances an oxyacetylene torch can be used to heat HSS components or parts ("hot working"), provided the critical 1,400 degrees Fahrenheit temperature is not exceeded. (Check the manufacturer's shop manual on this point because some say 1,000 degrees Fahrenheit (538 degrees Celsius) is the critical temperature.)

High-strength steels should be exposed to high temperatures from an oxyacetylene torch for only a very short period of time. Three minutes is the recommended maximum time span for exposing HSS to a 1,400-degree Fahrenheit (760 degrees Celsius) temperature to reduce the amount of scaling that normally takes place on the metal surface. High-temperature exposure causes discoloration as shown in Figure 7–116.

To determine and control temperatures of high-strength steel parts and components being "heat worked" with oxyacetylene equipment, it is necessary to use a temperature indicating crayon (Figure 7–117).

**Heat Crayons**

With steel, the use of heat is avoided whenever possible to prevent reducing the strength of the metal. With aluminum, heat must be used to restore flexibility caused by work hardening. If not, it will crack when straightening force is applied.

Before straightening, heat is often applied to the damaged area of the aluminum. It is easy to apply too much heat since aluminum does not change color with high temperatures. It also melts at a relatively low 1,220 degrees Fahrenheit (660 degrees Celsius). Careful heat control is very important.

**Heat crayons** or *thermal paint* can be used to determine the temperature of the aluminum or other metal being heated. They will melt at a specific temperature and warn you to prevent overheating.

The crayon or paint is applied next to the aluminum area to be heated. The mark will begin to melt when the crayon's or paint's melting point is almost reached. The melting will let you know that you are about to reach the melting point of the aluminum.

The metal should be marked closely adjacent to the area being worked with a crayon rated no more than 1,400 degrees Fahrenheit (760 degrees Celsius). Using such a crayon will indicate to the welder...
whether or not an excessive amount of heat is being applied. Thus metal temperatures can be controlled within safe levels and HSS damage easily prevented.

**CLEANING WITH A TORCH**

It is important before starting any weld that the surfaces to be joined must be thoroughly clean. The weld site must be completely free of any foreign material that might contaminate the weld. The finished weld is quite likely to be brittle, porous, and of poor integrity.

To remove heavy undercoating, rustproofing, tars, caulking, sealants, road dirt, and primers, first use a scraper to get off the loose material. Then use a scraper and an oxyacetylene torch. Then, if needed, use a wire brush and the torch, using a carburizing flame (Figure 7–118). In any event, keep the torch at a very low, controlled heat to prevent part damage. Use just enough heat to get the job done.

**FLAME ABNORMALITIES**

When changes occur during gas welding, such as overheating of the flame outlet, adhesion of spatter, or fluctuations in the gas adjustment pressure, the result will be variations in the flame and weld. Therefore, you must always be aware of the condition of the flame. Flame abnormalities, their causes, and remedies are described in Table 7–8.

### 7.15 BRAZING

**Brazing** is applied only to places for sealing. This is a method of welding in which a nonferrous metal,

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame Fluctuations</td>
<td>1. Moisture in the gas, condensation in hose.</td>
<td>1. Remove the moisture from the hose.</td>
</tr>
<tr>
<td></td>
<td>2. Insufficient acetylene supply.</td>
<td>2. Adjust the acetylene pressure and have the tank refilled.</td>
</tr>
<tr>
<td>Explosive Sound While Lighting the Torch</td>
<td>1. Oxygen or acetylene pressure is incorrect.</td>
<td>1. Adjust the pressure.</td>
</tr>
<tr>
<td></td>
<td>2. Removal of mixed-in gases are incomplete.</td>
<td>2. Remove the air from inside the torch.</td>
</tr>
<tr>
<td></td>
<td>3. The tip orifice is too enlarged.</td>
<td>3. Replace the tip.</td>
</tr>
<tr>
<td></td>
<td>4. The tip orifice is dirty.</td>
<td>4. Clean the orifice in the tip.</td>
</tr>
<tr>
<td>Flame Cut Off</td>
<td>1. Oxygen pressure is too high.</td>
<td>1. Adjust the oxygen pressure.</td>
</tr>
<tr>
<td></td>
<td>2. The flame outlet is clogged.</td>
<td>2. Clean the tip.</td>
</tr>
<tr>
<td>Popping Noises During Operation</td>
<td>1. The tip is overheated.</td>
<td>1. Cool the flame outlet (while letting a little oxygen flow).</td>
</tr>
<tr>
<td></td>
<td>2. The tip is clogged.</td>
<td>2. Clean the tip.</td>
</tr>
<tr>
<td></td>
<td>3. The gas pressure adjustment is incorrect.</td>
<td>3. Adjust the gas pressure.</td>
</tr>
<tr>
<td></td>
<td>4. Metal deposited on the tip.</td>
<td>4. Clean the tip.</td>
</tr>
<tr>
<td>Reversed Oxygen Flow (Oxygen is flowing into the path of the acetylene.)</td>
<td>1. The tip is clogged.</td>
<td>1. Clean the tip.</td>
</tr>
<tr>
<td></td>
<td>2. Oxygen pressure is too high.</td>
<td>2. Adjust the oxygen pressure.</td>
</tr>
<tr>
<td></td>
<td>3. Torch is defective. (The tip or valve is loose.)</td>
<td>3. Repair or replace the torch.</td>
</tr>
<tr>
<td></td>
<td>4. There is contact with the tip and the deposit metal.</td>
<td>4. Clean the orifice.</td>
</tr>
<tr>
<td>Backfire (There is a whistling noise and the torch handle grip gets hot. Flame is sucked into the torch.)</td>
<td>1. The tip is clogged or dirty.</td>
<td>1. Clean the tip.</td>
</tr>
<tr>
<td></td>
<td>2. Oxygen pressure is too low.</td>
<td>2. Adjust the oxygen pressure.</td>
</tr>
<tr>
<td></td>
<td>3. The tip is overheated.</td>
<td>3. Cool the tip with water (letting a little oxygen flow).</td>
</tr>
<tr>
<td></td>
<td>4. The tip orifice is enlarged or deformed.</td>
<td>4. Replace the tip.</td>
</tr>
<tr>
<td></td>
<td>5. A spark from the base metal enters the torch, causing an ignition of gas inside the torch.</td>
<td>5. Immediately shut off both torch valves. Let torch cool down. Then relight the torch.</td>
</tr>
<tr>
<td></td>
<td>6. Amount of acetylene flowing through the torch is too low.</td>
<td>6. Readjust the flow rate.</td>
</tr>
</tbody>
</table>
whose melting point (temperature) is lower than that of the base metal, is melted without melting the base metal (Figure 7-119). Brass brazing is frequently applied to automotive bodies.

Brazing is similar to joining two objects with adhesives; melted brass sufficiently spreads between the base metals to form a strong bond. Brazing joint strength is less than that of the base metal, but the same as the melted brass. Therefore, never use brazing as a structural joint unless recommended by the vehicle manufacturer.

There are two types of brazing:
- Soft brazing (soldering)
- Hard brazing (brass or nickel)

Ordinarily, the term brazing refers to hard brazing.

The basic characteristics of brazing are:

- The pieces of base metal are joined together at a relatively low temperature where the base metal does not melt. Therefore, there is a lower risk of distortion and stress in the base metal.
- Because the base metal does not melt, it is possible to join otherwise incompatible metals.
- Brazing metal has excellent flow characteristics; it penetrates well into narrow gaps and it is convenient for filling gaps in body seams.
- Since there is no penetration and the base metal is joined only at the surface, it has very low strength to resist repeated loads or impacts.
- Brazing is a relatively easy skill to master.

Automobile assembly plants sometimes use arc brazing to join the roof and quarter panels together (Figure 7-120). Arc brazing uses the same principles as MIG welding. However, argon is used with brazing metal instead of CO₂ or an argon/CO₂ mixture (Figure 7-121). Special brazing wire is also required. Since the amount of heat applied to the base metal is low, overheating is minimized. There is little distortion or warpage of the base metal. Compared to
TABLE 7-9

<table>
<thead>
<tr>
<th>Types of Brazing Materials</th>
<th>Main Ingredients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass brazing metal</td>
<td>Copper, Zinc</td>
</tr>
<tr>
<td>Silver brazing metal</td>
<td>Silver, Copper</td>
</tr>
<tr>
<td>Phosphor copper brazing metal</td>
<td>Copper, Phosphorus</td>
</tr>
<tr>
<td>Aluminum brazing metal</td>
<td>Aluminum, Silicon</td>
</tr>
<tr>
<td>Nickel brazing metal</td>
<td>Nickel, Chrome</td>
</tr>
</tbody>
</table>

flame brazing, arc brazing shortens both the time for making the weld and finishing. Also, there is no danger of lead poisoning.

In the body shop, the brazing equipment is usually the same as oxyacetylene welding. For brazing, an oxyacetylene torch, brass filler rods, flux welding goggles, gloves, and a torch lighter are needed. While the oxyacetylene torch can be used in soft brazing (soldering), it is best to use one designed for soldering.

To have brazing material with good qualities, such as flow characteristics, melting temperature, and compatibility with base metal and strength, it is made of two or more metals that form an alloy (Table 7-9). Copper and zinc are the main ingredients of the brazing rods used on auto bodies.

INTERACTION OF FLUX AND BRAZING RODS

Generally the surfaces of metals exposed to the atmosphere are covered with an oxidized film, which, if heat is applied, thickens. Flux not only removes this oxidized film, but prevents the metal surface from reoxidizing. It also increases the bond between the base metal and the brazing material.

If a brazing material is melted over a surface that has an oxidized film and foreign matter adhering to it, the brazing material will not adequately bond to the base metal. Surface tension will cause the brazing material to ball up and not stick to the base metal (Figure 7-122A).

The oxidized film can be removed by applying flux to the surface of the base metal and then heating it until it becomes liquid (Figure 7-122B). After the oxidation has been removed, the brazing material will adhere to the base metal and the flux will prevent further oxidation.

BRAZING JOINT STRENGTH

Since the strength of the brazing material is lower than that of the base metal, the shape of the joint and the clearance of the joint are extremely important. Figure 7-123 shows a basic brazing joint. Joint strength is dependent on the surface area of the pieces to be joined. Therefore, make the joint overlap as wide as possible.

Even when the items being joined are of the same material, the brazed surface area must be larger than that of a welded joint (Figure 7-124). As a general rule, the overlapping portion must be three or more times wider than the panel thickness.

BRAZING OPERATIONS

General brazing procedure is as follows:

1. Cleaning the base metal. If there is oxidation, oil, paint, or dirt on the surface of the base metal, clean the surfaces before brazing. These contaminants, if allowed to remain on the surface, can cause eventual joint failures. Even though flux acts to remove oxidized film and most
contaminants, it is not strong enough to completely remove everything. Therefore, first clean the surface mechanically with a wire brush.

2. **Flux application.** After the base metal is thoroughly cleaned, apply flux uniformly to the brazing surface. (If a brazing rod with flux in it is used (Figure 7–125), this operation is not necessary.)

3. **Base metal heating.** Heat the joining area of the base metal to a uniform temperature capable of accepting the brazing material (Figure 7–126). Adjust the torch flame so that it is a slight carburizing flame. By watching the melting flux, you can estimate the proper temperature for the brazing material.

4. **Base metal brazing operation.** When the base metal has reached the proper temperature, melt the brazing material onto the base metal (Figure 7–127). Let the braze metal flow out naturally. Stop heating the area when the brazing material has flowed into the gaps of the base metal.

Other points to consider are:

- Since brazing material flows easily over a heated surface, it is important to remember to heat the entire joining area to a uniform temperature.
- Do not melt the brazing material prior to heating the base metal because the brazing material will not adhere to the base metal.
- If the surface temperature of the base metal becomes too high, the flux will not clean the base metal, resulting in a poor brazing bond and inferior joint strength.

The following additional precautions should be taken when brazing:

- Brazing temperature must be higher than the melting point of brass by 50 to 190 degrees Fahrenheit (10 to 89 degrees Celsius).
- The size of the torch tip must be slightly larger than the thickness of the panel.
- Preheat the panel to deposit brazing filler metal more efficiently.
- Secure the panel to prevent the base metal from moving and the brazing zone from breaking.
- Evenly heat the portion to be welded without melting the base metal.
- Control the heat by tilting the torch more horizontally (flatter to surface) or by removing the flame and allowing the area to cool briefly.
- The brazing time must be as short as possible (to prevent weld strength from lowering).
- Avoid brazing the same place again.

**TREATMENT AFTER BRAZING**

Once the brazed portion has cooled down sufficiently, rinse off the remaining flux sediment with water. Scrub the surface with a stiff wire brush. Baked and
blackened flux can be removed with a sander or a sharp-pointed tool. If the remaining flux sediment is not adequately removed, the paint will not adhere properly. Corrosion and cracks might form in the joint.

7.16 SOLDERING
(SOFT BRAZING)

Soldering is not used to reinforce the panel joints. It is used only for final finishing, such as in leveling the panel surface and correcting the surface of the welded joints. Because soldering functions by “capillary phenomenon,” it has outstanding sealing ability.

Before attempting to solder a joint, remove paint, rust, oil, and other foreign substances.

SOLDERING PROCEDURE

After the surface has been thoroughly cleaned, proceed as follows:

1. Heat the portion to be soldered. Wipe it with a cloth after heating.
2. Stir solder paste well, and apply it with a brush. Apply it to an area 1 to 1 1/2 inches (25.4 to 38 mm) larger than the built-up area.
3. Heat it from a distance.
4. Wipe the solder paste from the center to the outside.
5. Make sure the soldered portion is silver gray. If it is bluish, it is due to overheating. If any spot is not soldered, reapply the paste for soldering.

When soldering, keep the following points in mind:

- It is desirable to use a special torch for soldering. If a gas welding torch is used, the oxygen and acetylene gas pressures must be 4.3 to 5.0 psi (29.7 to 34 kPa).
- The solder must contain at least 13 percent zinc.
- Maintain the appropriate temperature.
- Move the torch so that the flame evenly heats the entire portion to be soldered (without heating a single spot only).
- When the solder begins to melt, remove the flame and start finishing with a spatula.
- When additional solder is required, the previously built-up solder must be reheated.

7.17 PLASMA ARC CUTTING

Plasma arc cutting creates an intensely hot air stream, which melts and removes metal, over a very small area. Extremely clean cuts are possible with plasma arc cutting. Because of the tight focus of the heat, there is no warpage, even when cutting thin sheet metal.

Plasma arc cutting is replacing oxyacetylene as the best way to cut metals. It cuts damaged metal effectively and quickly but does not destroy the properties of the base metal. The old method of flame cutting just does not work that well anymore.

In plasma arc cutting, compressed air is often used for both shielding and cutting. As a shielding gas, air covers the outside area of the torch nozzle, cooling the area so the torch does not overheat.

Air also becomes the cutting gas. It swells around the electrode as it heads toward the nozzle opening. The swirling action helps to constrict and narrow the gas. When the machine is turned on, a pilot arc is formed between the nozzle and the inner electrode. When the cutting gas reaches this pilot arc, it is super heated—up to 60,000 degrees Fahrenheit (33,315 degrees Celsius).

Figure 7-128A shows that there are two areas for gas flow. In air plasma arc cutting, compressed air is used for both shielding and cutting. As a shield gas, air shields the outside area of the torch nozzle, cooling the area so the torch does not overheat. Air also becomes the cutting gas. The air swirls around the electrode as it heads toward the nozzle opening. The swirling action helps constrict and narrow the gas. When the machine is turned on, a pilot arc is formed between the nozzle and the inner electrode (Figure 7-128B). When the cutting gas reaches this pilot arc, it is super heated—up to 60,000 degrees Fahrenheit.

The gas is now so hot it ionizes and becomes capable of carrying an electrical current (ionized gas is actually the plasma). The small, narrow opening of the nozzle accelerates the expanding plasma toward the workpiece. When the workpiece is close enough, the arc crosses the gap, with the electrical current being carried by the plasma (Figure 7-128C). This is the cutting arc.

The extreme heat and force of the cutting arc melt a narrow path through the metal. This serves to dissipate the metal into gas and tiny particles. The force of the plasma literally blow away the metal particles, leaving a clean cut.

A 10- to 15-amp plasma arc cutter is generally adequate for mild steel up to 3/16 inch (5 mm) thick; a 30-amp unit can cut metal up to 1/4 inch (6 mm) thick; and a 60-amp unit will slice through metal up to 1/2 inch (13 mm) thick.

Controls are usually quite simple. Plasma arc cutters made specifically for thinner metals might only have an on/off switch and a ready light. More elaborate equipment can include a built-in air compressor, variable output control, on-board coolant, and other features.

On some units, a switch is provided that allows you to alter the current mode depending on the...
surface being cut. When cutting painted or rusty metal, a continuous high-frequency arc is best.

Two critical parts of the torch are the cutting nozzle and the electrode. These are the only consumables (besides air) in plasma arc cutting. If either the nozzle or the electrode is worn or damaged, the quality of the cut will be affected. They wear somewhat with each cut. Moisture in the air supply, cutting thick materials, or poor technique will make them fail more quickly. Keep a supply of electrodes and nozzles on hand and replace them when needed.

Today’s plasma arc cutters do an excellent job using clean, dry compressed air. The air can be supplied through an external or built-in air compressor or by using a cylinder of compressed air. Cylinders of air can be expensive, while shop air is almost free. To reduce contaminants, use a regulator with a filter.

Also, check the air pressure regularly. Using the wrong pressure can reduce the quality of the cuts, damage parts, and decrease the cutting capacity of the machine.

**OPERATING A PLASMA ARC CUTTER**

To operate a typical plasma arc cutter (Figure 7–129), proceed as follows:

1. Connect the unit to a clean, dry source of compressed air with a minimum line pressure of 60 psi (413 kPa) at the air connection.
2. Connect the torch and ground clamp to the unit. After plugging the machine in, connect the ground clamp to a clean metal surface on the vehicle. The clamp should be as close as possible to the area to be cut. Various types of clamps are shown in Figure 7–130.
3. Move the cutting nozzle into contact with an electrically conductive part of the work. This must be done to satisfy the work safety circuit.
4. Hold the plasma torch so that the cutting nozzle is perpendicular to the work surface (Figure 7–131). Push the plasma torch down. This will force the cutting nozzle down until it comes in contact with the electrode. Then the plasma arc will start. Release downward force on the torch to let the cutting nozzle return to its normal position. While keeping the cutting nozzle in light contact with the work, drag the gun lightly across the work surface.
5. Move the plasma torch in the direction the metal is to be cut. The speed of the cut will depend on the thickness of the metal. If the torch is moved too fast, it will not cut all the way through. If moved too slowly, it will put too much heat into the workpiece and might also extinguish the plasma arc.

**FIGURE 7–128** Note a typical plasma arc cutting setup. (A) Basic parts involved. (B) Pilot arc. (C) Cutting arc.
Other pointers that should be remembered when using a plasma arc cutter are:

1. When piercing materials 1/8 inch (3 mm) thick or more, angle the torch at 45 degrees until the plasma arc pierces the material. This will allow the stream of sparks to shoot off away from the gas diffuser.

If the torch is held perpendicular to the work when piercing heavy gauge material, the sparks will shoot back up at the gas diffuser. The molten metal will collect on the diffuser.

This might plug the air holes and shorten the life of the diffuser.

2. Torch cooling is important to extend the life of the electrode and nozzle. At the end of a cut, the air continues to flow for several seconds. This prevents the nozzle and electrode from

![Caution banner](image)

When angling the torch, be aware that the sparks can shoot as far as 20 feet (6 meters) away. Be sure that there are no combustibles or other workers in the area.

![Figure 7-130](image)

**Figure 7-130** Study the various types of clamps.

![Figure 7-131](image)

**Figure 7-131** When using a plasma arc cutter, be careful of molten metal spray on the backside of the cut. It could ignite and burn the interior parts of the vehicle.

(Courtesy of HTP America, Inc.)
overheating. Some equipment suppliers also recommend idling the unit for a couple of minutes after the cut is made.

3. When making long straight cuts, use a metal straightedge as a guide. Simply clamp it to the work to be cut. For elaborate cuts, make a template out of thin sheet metal or wood and guide the tip along that edge.

4. When cutting 1/4-inch (6 mm) materials, start the cut at the edge of the material.

5. When making rust repairs on cosmetic panels, it is possible to piece the new metal over the rusted area and then cut the patch panel at the same time that the rust is cut out. This process also works when splicing in a quarter panel.

6. Be aware of the fact that the sparks from the arc can damage painted surfaces and can also pit glass. Use a welding blanket to protect these surfaces.

7. Make sure there is nothing behind the panel that can be damaged. Check for wiring, fuel lines, sound deadening materials, and other objects that could cause a fire.

Remember that these variables will have a bearing on cut quality (Figure 7–132).

Travel speed. The thicker the material, the slower the speed. Travel is faster for thin material.

Parts wear. The tip and electrode will erode with use. The more wear, the poorer the quality of the cut.

Air quality. Moist or oil-contaminated air will contribute to a poor quality weld.

**PLASMA AIR CUTTER**

Some equipment (Figure 7–129) has a built-in safety protection system to protect the operator. This type of system cuts output power automatically if the safety cup is removed from the torch, if the tip and electrode are accidentally short circuited because of insufficient air pressure, or if the duty cycle is exceeded. The open circuit voltage of plasma cutting equipment can be very high (in the range of 250 to 300 volts), so insulated torches and internally connected terminals are also essential.

On some units, a switch is provided that allows you to alter the current mode when cutting bare or painted metal. When cutting painted or rusty metal,
a continuous high frequency arc is best for punching through the nonconductive surface layer and for keeping the arc going while cutting. When cutting bare metal, a high frequency arc is needed only to start the arc. Once the torch starts to cut, a direct current pilot arc is all that is needed to keep things going. The bare metal position gives the longest electrode and nozzle life.

**SUMMARY**

- There are three basic methods of joining metal together in the automobile assembly:
  - Mechanical (metal fastener) methods
  - Chemical (adhesive fastening) methods
  - Welding (molten metal) methods
  - Welding is one method of repair in which heat is applied to the pieces of metal to fuse them together into the shape desired.
- Visible weld penetration is indicated by the height of the exposed surface of the weld on the back side. Full weld penetration is needed to assure maximum weld strength.
- MIG welding is recommended by all OEMs, not only for HSS and unibody repair, but for all structural collision repair.
- The resistance spot welder provides very fast, high-quality welds while maintaining the best control of temperature buildup in adjacent panels and structure.
- Always follow service manual recommendations when welding. This will assure structural integrity.
- During the welding process, either inert gas or active gas shields the weld from the atmosphere and prevents oxidation of the base metal.
- Flat welding means the pieces are parallel with the bench or shop floor.
- Horizontal welding has the pieces turned sideways. Gravity tends to pull the puddle into the bottom piece. When welding a horizontal joint, angle the gun upward to hold the weld puddle in place against the pull of gravity.
- Vertical welding has the pieces turned upright. Gravity tends to pull the puddle down the joint. When welding a vertical joint, the best procedure is usually to start the arc at the top of the joint and pull downward with a steady drag.
- Overhead welding has the workpieces turned upside down. The tack weld is exactly that: a tack—a relatively small, temporary MIG spot weld that is used instead of a clamp or sheet metal screw to tack and hold the fit-up in place while a permanent weld is made.
- In a continuous weld, an uninterrupted seam or bead is laid down in a slow, steady, ongoing movement.
- A plug weld is made in a drilled or punched hole through the outside piece (or pieces).
- If welding defects should occur, think of ways to change your procedures to correct them.

**ASE-STYLE REVIEW QUESTIONS**

1. Technician A uses a forward gun angle to achieve a deep penetration in the metal. Technician B uses the reverse gun angle to achieve a flat bead. Who is correct?
   A. Technician A
   B. Technician B
   C. Both A and B
   D. Neither A nor B

2. Technician A says that the main function of the gun nozzle is to provide gas protection. Technician B says that if the insulation in the gun nozzle area is bypassed the current will ignite the inert shielding gas. Who is correct?
   A. Technician A
   B. Technician B
   C. Both A and B
   D. Neither A or B

3. Welding current affects which of the following?
   A. Base metal penetration depth
   B. Arc stability
   C. Amount of weld spatter
   D. All of the above

4. When MIG welding, what happens if the tip-to-base metal distance is too long?
   A. The shield gas effect is reduced.
   B. The wire protruding from the end of the gun increases and becomes preheated.
   C. The melting speed of the wire increases.
   D. All of the above
5. Technician A starts a butt weld in the center of the metal. Technician B says that it is wise not to weld more than 3/4 inch (19 mm) at one time. Who is correct?
   A. Technician A
   B. Technician B
   C. Both A and B
   D. Neither A nor B

6. Which of the following welds is the body shop alternative to the OEM resistance spot welds made at the factory?
   A. Spot
   B. Plug
   C. Stitch
   D. All of the above

7. What determines the length of a tack weld?
   A. Operator preference
   B. Thickness of the panel
   C. Type of base metal being welded
   D. Type of shielding gas being used

8. When using a resistance welder, Technician A installs a larger diameter electrode tip to increase the diameter of the spot weld. Technician B says that when the tips are worn, a tip dressing tool can be used to reshape the tips. Who is correct?
   A. Technician A
   B. Technician B
   C. Both A and B
   D. Neither A nor B

9. Which of the following statements concerning plasma arc cutting is incorrect?
   A. The plasma arc process cuts mangled metal effectively.
   B. Plasma cutting is an extension of the TIG process.
   C. The nozzle must come in contact with an electrically conductive part of the work before the arc can start.
   D. When piercing material that is more than 1/8 inch (3.1 mm) thick, hold the torch perpendicular to the work.

10. The typical acetylene pressure for oxyacetylene welding is
    A. 15 to 100 psi (103 to 689 kPa)
    B. 3 to 12 psi (21 to 83 kPa)
    C. 3 to 25 psi (21 to 173 kPa)
    D. 30 to 120 psi (207 to 827 kPa)

11. Mixing slightly more acetylene than oxygen will obtain what type of flame?
    A. Neutral
    B. Standard
    C. Carburizing
    D. Oxidizing

12. Which of the following is not characteristic of brazing?
    A. Relatively high strength
    B. Can join parts of varying thickness
    C. Greater risk of distortion in the base metal
    D. Can join otherwise incompatible metals

13. When operating an MIG welder, which of the following indicates the correct wire-to-heating ratio?
    A. An even, high-pitched buzzing sound
    B. A steady, reflected light
    C. Both A and B
    D. Neither A nor B

14. Technician A says that all steels can be MIG welded with one common type of weld wire. Technician B says that metals of different thicknesses can be MIG welded with the same diameter wire. Who is correct?
    A. Technician A
    B. Technician B
    C. Both A and B
    D. Neither A nor B

ESSAY QUESTIONS
1. Summarize the MIG process.
2. Describe basic guidelines when MIG welding aluminum.

CRITICAL THINKING PROBLEMS
1. If undercutting occurs while MIG welding, what should you do?
2. What can be done to prevent heat build-up during welding?

MATH PROBLEMS
1. When setting up a typical plasma arc cutter, the air pressure gauge shows only 20 psi (138 kPa). How much should this pressure be changed?
2. During a butt weld on a thin panel, the technician has welded 1/4 inch (6.4 mm). How much further can he or she go before stopping to allow cooling?