Chapter 4

Shielded Metal Arc Welding of Plate

OBJECTIVES

After completing this chapter, the student should be able to

✓ set the welding amperage correctly.
✓ explain the effect of changing arc length on a weld.
✓ control weld bead contour during welding by using the proper weave pattern.
✓ demonstrate an ability to control undercut, overlap, porosity, and slag inclusions when welding.
✓ explain the effect of electrode angle on a weld.

KEY TERMS

amperage range
arc length
cellulose-based fluxes
chill plate
electrode angle
lap joint
mineral-based fluxes
rutile-based fluxes
square butt joint
stringer bead
tee joint
weave pattern

INTRODUCTION

Shielded metal arc welding (SMAW), or stick welding, is the most often used method of joining plate. This method provides a high temperature and concentration of heat, which allow a small molten weld pool to be built up quickly. The addition of filler metal from the electrode adds reinforcement and increases the strength of the weld. SMAW can be performed on almost any type of metal 1/8 in. (3 mm) thick or thicker. A minimum of equipment is required, and it can be portable.

High-quality welds can be consistently produced on almost any type of metal and in any position. The quality of the welds produced depends largely upon the skill of the welder. Developing the necessary skill level requires practice. However, practicing the welds repeatedly without changing techniques will not aid in developing the required skills. Each time a weld is completed it should be evaluated, and then a change should be made in the technique to improve the next weld.
PRACTICE 4-1
Shielded Metal Arc Welding Safety

Using a welding work station, welding machine, welding electrodes, welding helmet, eye and ear protection, welding gloves, proper work clothing, and any special protective clothing that may be required, demonstrate, to your instructor and other students, the safe way to prepare yourself and the welding work station for welding. Include in your demonstration appropriate references to burn protection, eye and ear protection, material specification data sheets, ventilation, electrical safety, general work clothing, special protective clothing, and area clean-up.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

EXPERIMENT 4-1
Striking the Arc

Using a properly set up and adjusted arc welding machine, the proper safety protection, as demonstrated in Practice 4-1, E6011 welding electrodes having a 1/8-in. (3-mm) diameter, and one piece of mild steel plate, 1/4-in. (6-mm) thick, you will practice striking an arc, Figure 4-1.

With the electrode held over the plate, lower your helmet. Scratch the electrode across the plate (like striking a large match), Figure 4-2. As the arc is established, slightly raise the electrode to the desired arc length. Hold the arc in one place until the molten weld pool builds to the desired size. Slowly lower the electrode as it burns off and move it forward to start the bead.

If the electrode sticks to the plate, quickly squeeze the electrode holder lever to release the electrode. Break the electrode free by bending it back and forth a few times. Do
not touch the electrode without gloves, because it will still be hot. If the flux breaks away from the end of the electrode, throw out the electrode because restarting the arc will be very difficult, Figure 4-3.

Break the arc by rapidly raising the electrode after completing a 1-in. (25-mm) weld bead. Restart the arc as you did before, and make another short weld. Repeat this process until you can easily start the arc each time. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.◆

**EXPERIMENT 4-2**

**Striking the Arc Accurately**

Using the same materials and setup as described in Experiment 4-1, you will start the arc at a specific spot in order to prevent damage to the surrounding plate.

Hold the electrode over the desired starting point. After lowering your helmet, swiftly bounce the electrode against the plate, Figure 4-4. A lot of practice is required to develop the speed and skill needed to prevent the electrode from sticking to the plate.

A more accurate method of starting the arc involves holding the electrode steady by resting it on your free hand like a pool cue. The electrode is rapidly pushed forward so that it strikes the metal exactly where it should. This is an excellent method of striking an arc. Striking an arc in an incorrect spot may cause damage to the base metal.

Practice starting the arc until you can start it within 1/4 in. (6 mm) of the desired location. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.◆

**Effect of Too High or Too Low Current Settings**

Each welding electrode must be operated in a particular current (amperage) range, Table 4-1. Welding with the current set too low results in poor fusion and poor arc stability, Figure 4-5. The weld may have slag or gas inclusions because the molten weld pool was not fluid long enough for the flux to react. Little or no penetration of the weld into the...

<table>
<thead>
<tr>
<th>Electrode Classification</th>
<th>E6010</th>
<th>E6011</th>
<th>E6012</th>
<th>E6013</th>
<th>E7016</th>
<th>E7018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/32 in. (2.4 mm)</td>
<td>40–80</td>
<td>50–70</td>
<td>40–90</td>
<td>40–85</td>
<td>75–105</td>
<td>70–110</td>
</tr>
<tr>
<td>1/8 in. (3.2 mm)</td>
<td>70–130</td>
<td>85–125</td>
<td>75–130</td>
<td>70–120</td>
<td>100–150</td>
<td>90–165</td>
</tr>
<tr>
<td>5/32 in. (4 mm)</td>
<td>110–165</td>
<td>130–160</td>
<td>120–200</td>
<td>130–160</td>
<td>140–190</td>
<td>125–220</td>
</tr>
</tbody>
</table>

**Table 4-1** Welding amperage range.
Shielded Metal Arc Welding

base plate may also be evident. With the current set too low, the arc length is very short. A very short arc length results in frequent shortening and sticking of the electrode.

The core wire of the welding electrode is limited in the amount of current it can carry. As the current is increased, the wire heats up because of electrical resistance. This pre-heating of the wire causes some of the chemicals in the covering to be burned out too early, Figure 4-6. The loss of the proper balance of elements causes poor arc stability. This condition leads to spatter, porosity, and slag inclusions.

An increase in the amount of spatter is also caused by a longer arc. The weld bead made at a high amperage setting is wide and flat with deep penetration. The spatter is excessive and is mostly hard. The spatter is called hard because it fuses to the base plate and is difficult to remove, Figure 4-7. The electrode covering is discolored more than 1/8 in. (3 mm) to 1/4 in. (6 mm) from the end of the electrode. Extremely high settings may also cause the electrode to discolor, crack, glow red, or burn.

EXPERIMENT 4-3

Effects of Amperage Changes on a Weld Bead

For this experiment, you will need an arc welding machine, welding gloves, safety glasses, welding helmet, appropriate clothing, E6011 welding electrodes having a 1/8-in. (3-mm) diameter, and one piece of mild steel plate, 1/4 in. (6 mm) to 1/2 in. (13 mm) thick. You will observe what happens to the weld bead when the amperage settings are raised and lowered.

Starting with the machine set at approximately 90 A AC or DCRP, strike an arc and make a weld 1 in. (25 mm) long. Break the arc. Raise the current setting by 10 A, strike an arc, and make another weld 1 in. (25 mm) long. Repeat this procedure until the machine amperage is set at the maximum value.

Replace the electrode and reset the machine to 90 A. Make a weld 1 in. (25 mm) long. Stop and lower the current setting by 10 A. Repeat this procedure until the machine amperage is set at a minimum value.

Cool and chip the plate, comparing the different welds for width, buildup, molten weld pool size, spatter, slag removal, and penetration, Figure 4-8 (A) and (B). In addition, compare the electrode stubs. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.
Electrode Size and Heat

The selection of the correct size of welding electrode for a weld is determined by the skill of the welder, the thickness of the metal to be welded, and the size of the metal. Using small diameter electrodes requires less skill than using large diameter electrodes. The deposition rate, or the rate that weld metal is added to the weld, is slower when small diameter electrodes are used. Small diameter electrodes will make acceptable welds on thick plate, but more time is required to make the weld.

Large diameter electrodes may overheat the metal if they are used with thin or small pieces of metal. To determine if a weld is too hot, watch the shape of the trailing edge of the molten weld pool, Figure 4-9. Rounded ripples indicate the weld is cooling uniformly and that the heat is not excessive. If the ripples are pointed, the weld is cooling too slowly because of excessive heat. Extreme overheating can cause a burnthrough, which is hard to repair.

To correct an overheating problem, a welder can turn down the amperage, use a shorter arc, travel at a faster rate, use a chill plate (a large piece of metal used to absorb excessive heat), or use a smaller electrode at a lower current setting.

**EXPERIMENT 4-4**

**Excessive Heat**

Using a properly set up and adjusted arc welding machine, the proper safety protection, E6011 welding electrodes having a 1/8-in. (3-mm) diameter, and three pieces of mild steel plate, 1/8 in. (3 mm), 3/16 in. (4.8 mm), and 1/4 in. (6 mm) thick, you will observe the effects of overheating on the weld. Make a stringer weld on each of the three plates using the same amperage setting, travel rate, and arc length for each weld. Cool and chip the welds. Then compare the weld beads for width, reinforcement, and appearance.

Using the same amperage settings, make additional welds on the 1/8-in. (3-mm) and 3/16-in. (4.8-mm) plates. Vary the arc lengths and travel speeds for these welds. Cool and chip each weld and compare the beads for width, reinforcement, and appearance. Make additional welds on the 1/8-in. (3-mm) and 3/16-in. (4.8-mm) plates, using the same arc length and travel speed as in the earlier part of this experiment, but at a lower amperage setting. Cool and chip the welds and compare the beads for width, reinforcement, and appearance.

The plates should be cooled between each weld so that the heat from the previous weld does not affect the test results. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

**Arc Length**

The arc length is the distance the arc must jump from the end of the electrode to the plate or weld pool surface. As the weld progresses, the electrode becomes shorter as it is consumed. To maintain a constant arc length, the electrode must be lowered continuously. Maintaining a constant arc length is important, as too great a change in the arc length will adversely affect the weld.

As the arc length is shortened, metal transferring across the gap may short out the electrode, causing it to stick to the plate. The weld that results is narrow and has a high buildup, Figure 4-10.

Long arc lengths produce more spatter because the metal being transferred may drop outside of the molten weld pool. The weld is wider and has little buildup, Figure 4-11.

There is a narrow range for the arc length in which it is stable, metal transfer is smooth, and the bead shape is controlled. Factors affecting the length are the type of electrode, joint design, metal thickness, and current setting.
Some welding electrodes, such as E7024, have a thick flux covering. The rate at which the covering melts is slow enough to permit the electrode coating to be rested against the plate. The arc burns back inside the covering as the electrode is dragged along touching the joint, Figure 4-12. For this type of welding electrode, the arc length is maintained by the electrode covering.

An arc will jump to the closest metal conductor. On joints that are deep or narrow, the arc is pulled to one side and not to the root, Figure 4-13. As a result, the root fusion is reduced or may be nonexistent, thus causing a poor weld. If a very short arc is used, the arc is forced into the root for better fusion.

Because shorter arcs produce less heat and penetration, they are best suited for use on thin metal or thin-to-thick metal joints. Using this technique, metal as thin as 16 gauge can be arc welded easily. Higher amperage settings are required to maintain a short arc that gives good fusion with a minimum of slag inclusions. The higher settings, however, must be within the amperage range for the specific electrode.

Finding the correct arc length often requires some trial and adjustment. Most welding jobs require an arc length of 1/8 in. (3 mm) to 3/8 in. (10 mm), but this distance varies. It may be necessary to change the arc length when welding to adjust for varying welding conditions.

**EXPERIMENT 4-5**

**Effect of Changing the Arc Length on a Weld**

Using an arc welding machine, welding gloves, safety glasses, welding helmet, appropriate clothing, E6011 welding electrodes having a 1/8-in. (3-mm) diameter, and one piece of mild steel plate, 1/4 in. (6 mm) to 1/2 in. (13 mm) thick, you will observe the effect of changing the arc length on a weld.

Starting with the welding machine set at approximately 90 A AC or DCRP, strike an arc and make a weld 1 in. (25 mm) long. Continue welding while slowly increasing the arc length until the arc is broken. Restart the arc and make another weld 1 in. (25 mm) long. Welding should again be continued while slowly shortening the arc length until the arc stops. Quickly break the electrode free from the plate, or release the electrode by squeezing the lever on the electrode holder.

Cool and chip both welds. Compare both welding beads for width, reinforcement, uniformity, spatter, and appearance. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

**Electrode Angle**

The electrode angle is measured from the electrode to the surface of the metal. The term used to identify the electrode angle is affected by the direction of travel, generally leading or trailing, Figure 4-14. The relative angle is important because there is a jetting force blowing the metal and flux from the end of the electrode to the plate.

**Leading Angle** A leading electrode angle pushes molten metal and slag ahead of the weld, Figure 4-15. When welding in the flat position, caution must be taken to prevent cold lap and slag inclusions. The solid metal ahead of the weld cools and solidifies the molten filler metal and slag before they can melt the solid metal. This rapid cooling prevents the metals from fusing together,
Figure 4-16. As the weld passes over this area, heat from the arc may not melt it. As a result, some cold lap and slag inclusions are left.

The following are suggestions for preventing cold lap and slag inclusions:
- Use as little leading angle as possible.
- Ensure that the arc melts the base metal completely, Figure 4-17.

EXPERIMENT 4-6
Effect of Changing the Electrode Angle on a Weld

Using a properly set up and adjusted arc welding machine, the proper safety protection, E6011 welding
FIGURE 4-18 Effect of a leading angle on weld bead buildup, width, and penetration. As the angle increases toward the vertical position (C), penetration increases.

FIGURE 4-19 Trailing electrode angle.

FIGURE 4-20 Effect of a trailing angle on weld bead buildup, width, and penetration. Section A-A shows more weld buildup due to a greater angle of the electrode.
electrodes having a 1/8-in. (3-mm) diameter, and one piece of mild steel plate, 1/4 in. (6 mm) to 1/2 in. (13 mm) thick, you will observe the effect of changes in the electrode angle on a weld.

Start welding with a sharp trailing angle. Make a weld about 1 in. (25 mm) long. Closely observe the molten weld pool at the points shown in Figure 4-21. Slowly increase the electrode angle and continue to observe the weld.

When you reach a 90° electrode angle, make a weld about 1 in. (25 mm) long. Observe the parts of the weld molten weld pool as shown in Figure 4-21.

Continue welding and change the electrode angle to a sharp leading angle. Observe the weld molten weld pool at the points shown in Figure 4-22.

During this experiment, you must maintain a constant arc length, travel speed, and weave pattern if the observations and results are to be accurate.

Cool and chip the weld. Compare the weld bead for uniformity in width, reinforcement, and appearance. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

Electrode Manipulation

The movement or weaving of the welding electrode can control the following characteristics of the weld bead: penetration, buildup, width, porosity, undercut, overlap, and slag inclusions. The exact weave pattern for each weld is often the personal choice of the welder. However, some patterns are especially helpful for specific welding situations. The pattern selected for a flat (1G) butt joint is not as critical as is the pattern selection for other joints and other positions.

Many weave patterns are available for the welder to use. Figure 4-23 shows ten different patterns that can be used for most welding conditions.

The circular pattern is often used for flat position welds on butt, tee, outside corner joints, and for buildup or surfacing applications. The circle can be made wider or longer to change the bead width or penetration, Figure 4-24.

The “C” and square patterns are both good for most 1G (flat) welds, but can also be used for vertical (3G) positions. These patterns can also be used if there is a large gap to be filled when both pieces of metal are nearly the same size and thickness.

The “J” pattern works well on flat (1F) lap joints, all vertical (3G) joints, and horizontal (2G) butt and lap (2F) welds. This pattern allows the heat to be concentrated on the thicker plate, Figure 4-25. It also allows the reinforcement to be built up on the metal deposited during the first part of the pattern. As a result, a uniform bead contour is maintained during out-of-position welds.
The “T” pattern works well with fillet welds in the vertical (3F) and overhead (4F) positions, Figure 4-26. It also can be used for deep groove welds for the hot pass. The top of the “T” can be used to fill in the toe of the weld to prevent undercutting.

The straight step pattern can be used for stringer beads, root pass welds, and multiple pass welds in all positions. For this pattern, the smallest quantity of metal is molten at one time as compared to other patterns. Therefore, the weld is more easily controlled. At the same time that the electrode is stepped forward, the arc length is increased so that no metal is deposited ahead of the molten weld pool, Figure 4-27 and Figure 4-28. This action allows the molten weld pool to cool to a controllable size. In addition, the arc burns off any paint, oil, or dirt from the metal before it can contaminate the weld.

The figure 8 pattern and the zigzag pattern are used as cover passes in the flat and vertical positions. Do not weave more than 2 1/2 times the width of the electrode.

These patterns deposit a large quantity of metal at one time. A shelf can be used to support the molten weld pool when making vertical welds using either of these patterns, Figure 4-29.
Positioning of the Welder and the Plate

The welder should be in a relaxed, comfortable position before starting to weld. A good position is important for both the comfort of the welder and the quality of the welds. Welding in an awkward position can cause welder fatigue, which leads to poor welder coordination and poor-quality welds. Welders must have enough freedom of movement so that they do not need to change position during a weld. Body position changes should be made only during electrode changes.

When the welding helmet is down, the welder is blind to the surroundings. Due to the arc, the field of vision of the welder is also very limited. These factors often cause the welder to sway. To stop this swaying, the welder should lean against or hold on to a stable object. When welding, even if a welder is seated, touching a stable object will make that welder more stable and will make welding more relaxing.

Welding is easier if the welder can find the most comfortable angle. The welder should be in either a seated or a standing position in front of the welding table. The welding machine should be turned off. With an electrode in place in the electrode holder, the welder can draw a straight line along the plate to be welded. By turning the plate to several different angles, the welder should be able to determine which angle is most comfortable for welding, Figure 4-30.

Practice Welds

Practice welds are grouped according to the type of joint and the type of welding electrode. The welder or instructor should select the order in which the welds are made. The stringer beads should be practiced first in each position before the welder tries the different joints in each position. Some time can be saved by starting with the stringer beads. If this is done, it is not necessary to cut or tack the plate together, and a number of beads can be made on the same plate.

Students will find it easier to start with butt joints. The lap, tee, and outside corner joints are all about the same level of difficulty.

Starting with the flat position allows the welder to build skills slowly, so that out-of-position welds become easier to do. The horizontal tee and lap welds are almost as easy to make as the flat welds. Overhead welds are as simple to make as vertical welds, but they are harder to position. Horizontal butt welds are more difficult to perform than most other welds.

Electrodes Arc welding electrodes used for practice welds are grouped into three filler metal (F number) classes according to their major welding characteristics. The groups are E6010 and E6011, E6012 and E6013, and E7016 and E7018.

F3 E6010 and E6011 Electrodes

Both of these electrodes have cellulose-based fluxes. As a result, these electrodes have a forceful arc with little slag left on the weld bead.

F2 E6012 and E6013 Electrodes

These electrodes have rutile-based fluxes, giving a smooth, easy arc with a thick slag left on the weld bead.

F4 E7016 and E7018 Electrodes

Both of these electrodes have a mineral-based flux. The resulting arc is smooth and easy, with a very heavy slag left on the weld bead.

The cellulose- and rutile-based groups of electrodes have characteristics that make them the best electrodes for starting specific welds. The electrodes with the cellulose-based fluxes do not have heavy slags that may interfere with the welder’s view of the weld. This feature is an advantage for flat tee and lap joints. Electrodes with the rutile-based fluxes (giving an easy arc with low spatter) are easier to control and are used for flat stringer beads and butt joints.

Unless a specific electrode has been required by a Welding Procedure Specification (WPS), welders can select what they consider to be the best electrode for a specific weld. Without a WPS a recommendation can be made and should be tried, but often the welder has the final choice. An accomplished welder can make...
defect-free welds on all types of joints using all types of electrodes in any weld position.

Electrodes with mineral-based fluxes should be the last choice. Welds with a good appearance are more easily made with these electrodes, but strong welds are hard to obtain. Without special care being taken during the start of the weld, porosity will be formed in the weld. Figure 4-31 shows a starting tab used to prevent this porosity from becoming part of the finished weld. More information on electrode selection can be found in Chapter 18.

**Stringer Beads**

A straight weld bead on the surface of a plate, with little or no side-to-side electrode movement, is known as a stringer bead. Stringer beads are used by students to practice maintaining arc length, weave patterns, and electrode angle so that their welds will be straight, uniform, and free from defects. Stringer beads, Figure 4-32, are also used to set the machine amperage and for buildup or surfacing applications.

The stringer bead should be straight. A beginning welder needs time to develop the skill of viewing the entire welding area. At first, the welder sees only the arc, Figure 4-33. With practice, the welder begins to see parts of the molten weld pool. After much practice, the welder will see the molten weld pool (front, back, and both sides), slag, buildup, and the surrounding plate, Figure 4-34. Often, at this skill level, the welder may not even notice the arc.

A straight weld is easily made once the welder develops the ability to view the entire welding zone. The welder will occasionally glance around to ensure that the weld is straight. In addition, it can be noted if the weld is uniform and free from defects. The ability of the welder to view the entire weld area is demonstrated by making consistently straight and uniform stringer beads.

After making practice stringer beads, a variety of weave bead patterns should be practiced to gain the ability to control the molten weld pool when welding out-of-position.

**PRACTICE 4-2**

**Straight Stringer Beads in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes**

Using a properly set up and adjusted arc welding machine, proper safety protection, as demonstrated in Practice 4-1, arc welding electrodes with a 1/8-in. (3mm)
Chapter 4  Shielded Metal Arc Welding of Plate

A diameter, and one piece of mild steel plate, 6 in. (152 mm) long × 1/2 in. (6 mm) thick, you will make straight stringer beads.

- Starting at one end of the plate, make a straight weld the full length of the plate.
- Watch the molten weld pool at this point, not the end of the electrode. As you become more skillful, it is easier to watch the molten weld pool.
- Repeat the beads with all three (F) groups of electrodes until you have consistently good beads.
- Cool, chip, and inspect the bead for defects after completing it. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

PRACTICE 4-3

Stringer Beads in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-2, you will make vertical up stringer beads. Start with the plate at a 45° angle.

This technique is the same as that used to make a vertical weld. However, a lower level of skill is required at 45°, and it is easier to develop your skill. After the welder masters the 45° angle, the angle is increased successively until a vertical position is reached, Figure 4-35.

Before the molten metal drips down the bead, the back of the molten weld pool will start to bulge, Figure 4-36. When this happens, increase the speed of travel and the weave pattern.

Cool, chip, and inspect each completed weld for defects. Repeat the beads as necessary with all three (F) groups of electrodes until consistently good beads are obtained in this position. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

PRACTICE 4-4

Horizontal Stringer Beads Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-2, you will make horizontal stringer beads on a plate.

When the welder begins to practice the horizontal stringer bead, the plate may be reclined slightly, Figure 4-37. This placement allows the welder to build the
required skill by practicing the correct techniques successfully. The “J” weave pattern is suggested for this practice. As the electrode is drawn along the straight back of the “J,” metal is deposited. This metal supports the molten weld pool, resulting in a bead with a uniform contour, Figure 4-38.

Angling the electrode up and back toward the weld causes more metal to be deposited along the top edge of the weld. Keeping the bead small allows the surface tension to hold the molten weld pool in place.

Gradually increase the angle of the plate until it is vertical and the stringer bead is horizontal. Repeat the beads as needed with all three (F) groups of electrodes until consistently good beads are obtained in this position. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

**Square Butt Joint**

The **square butt joint** is made by tack welding two flat pieces of plate together, Figure 4-39. The space between the plates is called the root opening or root gap. Changes in the root opening will affect penetration. As the space increases, the weld penetration also increases. The root opening for most butt welds will vary from 0 in. (0 mm) to 1/8 in. (3 mm). Excessively large openings can cause burn-through or a cold lap at the weld root, Figure 4-40.
After a butt weld is completed, the plate can be cut apart so it can be used for rewelding. The strips for butt welding should be no smaller than 1 in. (25 mm) wide. If they are too narrow, there will be a problem with heat buildup.

If the plate strips are no longer flat after the weld has been cut out, they can be tack welded together and flattened with a hammer, Figure 4-41.

**PRACTICE 4-5**

Welded Square Butt Joint in the Flat Position (1G) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, arc welding electrodes having a 1/8-in. (3-mm) diameter, and two or more pieces of mild steel plate, 6 in. (152 mm) long × 1/4 in. (6 mm) thick, you will make a welded square butt joint in the flat position, Figure 4-42.

Tack weld the plates together and place them flat on the welding table. Starting at one end, establish a molten weld pool on both plates. Hold the electrode in the molten weld pool until it flows together, Figure 4-43. After the gap is bridged by the molten weld pool, start weaving the electrode slowly back and forth across the joint. Moving the electrode too quickly from side to side may result in slag being trapped in the joint, Figure 4-44.

Continue the weld along the 6-in. (152-mm) length of the joint. Normally, deep penetration is not required for this type of weld. If full plate penetration is required, the edges of the butt joint should be beveled or a larger than normal root gap should be used. Cool, chip, and inspect the weld for uniformity and soundness. Repeat

---

**Figure 4-41** After the plates are tack welded together, they can be forced into alignment by striking them with a hammer.

**Figure 4-42** Square butt joint in the flat position.
Section 2 Shielded Metal Arc Welding

the welds as needed to master all three (F) groups of electrodes in this position. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ♦

PRACTICE 4-6

Vertical (3G) Up-Welded Square Butt Weld Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-5, you will make vertical up-welded square butt joints.

With the plates at a 45° angle, start at the bottom and make the molten weld pool bridge the gap between the plates, Figure 4-45. Build the bead size slowly so that the molten weld pool has a shelf for support. The “C,” “J,” or square weave pattern works well for this joint.

As the electrode is moved up the weld, the arc is lengthened slightly so that little or no metal is deposited ahead of the molten weld pool. When the electrode is brought back into the molten weld pool, it should be lowered to deposit metal, Figure 4-46.

As skill is developed, increase the plate angle until it is vertical. Cool, chip, and inspect the weld for uniformity and defects. Repeat the welds with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ♦

PRACTICE 4-7

Welded Horizontal (2G) Square Butt Weld Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as described in Practice 4-5, you will make a welded horizontal square butt joint.

- Start practicing these welds with the plate at a slight angle.
- Strike the arc on the bottom plate and build the molten weld pool until it bridges the gap.

If the weld is started on the top plate, slag will be trapped in the root at the beginning of the weld because of poor initial penetration. The slag may cause the weld to crack when it is placed in service.

The “J” weave pattern is recommended in order to deposit metal on the lower plate so that it can support
the bead. By pushing the electrode inward as you cross the gap between the plates, deeper penetration is achieved.

As you acquire more skill, gradually increase the plate angle until it is vertical and the weld is horizontal.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

**Edge Weld**

An edge weld joint is made by placing the edges of the plate evenly, Figure 4-47. When assembling the edge joint
Clamp the plates flat together and make a tack weld along each end of the plates.

Starting at one end of the plate, make a straight weld the full length of the plate. Make the weld bead as wide as the width of the edge joint.

Watch the molten weld pool, not the end of the electrode.

Cool, chip, and inspect the weld for uniformity and defects.

Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects.

Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

**PRACTICE 4-9**

**Edge Joint in the Vertical Down Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes**

Using the same setup, materials, and electrodes as listed in Practice 4-8, you will make a vertical down weld on an edge joint. Start with the plates at a 45° angle.

This technique is the same as that used to make vertical down welds. However, a lower level of skill is required at 45°, and it is easier to develop your skill. After you master the 45° angle, the angle is increased successively until a vertical position is reached, Figure 4-51.

- Make the weld bead as wide as the joint.
- Controlling a weld bead this size is more difficult, but you must develop the skill required to control this larger molten weld pool.
- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

**PRACTICE 4-10**

**Edge Joint in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes**

Using the same setup, materials, and electrodes as listed in Practice 4-8, you will make a vertical up weld on an edge joint. Start with the plates at a 45° angle.
**Figure 4-50** Practice 4-8 edge joint.

**Figure 4-51** Vertical down.
This technique is the same as that used to make vertical up welds. However, a lower level of skill is required at 45°, and it is easier to develop your skill. After you master the 45° angle, the angle is increased successively until a vertical position is reached, Figure 4-52.

Before the molten metal drips down the bead, the back of the molten weld pool will start to bulge, Figure 4-53. When this happens, increase the speed of travel and the weave pattern.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ♦

### PRACTICE 4-11

#### Edge Joint in the Horizontal Position

Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-8, you will make a horizontal weld on an edge joint. When you begin to practice the horizontal weld, the plate may be reclined slightly, Figure 4-54. This placement allows the welder to build the required skill by practicing the correct techniques successfully. The “J” weave or stepped pattern is suggested for this practice. As the electrode is drawn back to the back edge of the weld pool, metal is deposited. Use the metal being deposited to support the molten weld pool.

Angling the electrode up and back toward the weld causes more metal to be deposited along the top edge of the weld. Keeping the bead small allows the surface tension to hold the molten weld pool in place.

Gradually increase the angle of the plate until it and the weld bead are horizontal.

- Cool, chip, and inspect the weld for uniformity and defects.
Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

**PRACTICE 4-12**

Edge Joint in the Overhead Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-8, you will make an overhead weld on an edge joint.

- With the electrode pointed in a slightly trailing angle, Figure 4-55, strike the arc in the joint.
- Keep a very short arc length.
- Use the stepped pattern and move the electrode forward slightly when the molten weld pool grows to the correct size, Figure 4-56.

As the molten weld pool gets larger it has a tendency to quickly become convex. If you keep the arc in the molten weld pool once the joint is filled and the weld face is flat it will quickly overfill and become convex. This can result in the weld face forming drips of metal hanging from the weld like icicles, Figure 4-57.

- When the molten weld pool cools and begins to shrink, move the arc back near the center of the weld.
- Hold the arc in this new location until the molten weld pool again grows to the correct size.
- Step the electrode forward again and keep repeating this pattern until the weld progresses along the entire weld joint length.
- Cool, chip, and inspect the weld for uniformity and defects.
Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

Outside Corner Joint

An outside corner joint is made by placing the plates at a 90° angle to each other, with the edges forming a V groove, Figure 4-58. There may or may not be a slight root opening left between the plate edges. Small tack welds should be made approximately 1/2 in. (13 mm) from both ends of the joint.

The weld bead should completely fill the V groove formed by the plates and may have a slightly convex surface buildup. The back side of an outside corner joint can be used to practice fillet welds, or four plates can be made into a box tube shape, Figure 4-59.

PRACTICE 4-13

Outside Corner Joint in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, as demonstrated in Practice 4-1, arc welding electrodes with a 1/8-in. (3-mm) diameter, and two pieces of mild steel plate 6 in. (152 mm) long × 1/4 in. (6 mm) thick, you will make a weld on an outside corner joint.

- Starting at one end of the plate, make a straight weld the full length of the plate.
- Watch the molten weld pool at this point, not the end of the electrode. As you become more skillful, it is easier to watch the molten weld pool.
- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

Figure 4-58 V formed by an outside corner joint.

Figure 4-59 Box tube made from four outside corner joint welds.
PRACTICE 4-14
Outside Corner Joint in the Vertical Down Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-13, you will make a vertical down weld on an outside corner joint. Start with the plate at a 45° angle.

This technique is the same as that used to make vertical down welds. However, a lower level of skill is required at 45°, and it is easier to develop your skill. After you master the 45° angle, the angle is increased successively until a vertical position is reached, Figure 4-60.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

PRACTICE 4-15
Outside Corner Joint in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-13, you will make a vertical up weld on an outside corner joint. Start with the plate at a 45° angle.

This technique is the same as that used to make vertical up welds. However, a lower level of skill is required at 45°, and it is easier to develop your skill. After the welder masters the 45° angle, the angle is increased successively until a vertical position is reached, Figure 4-61.

Before the molten metal drips down the bead, the back of the molten weld pool will start to bulge, Figure 4-62. When this happens, increase the speed of travel and the weave pattern.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

PRACTICE 4-16
Outside Corner Joint in the Horizontal Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-13, you will make a horizontal weld on an outside corner joint. When the welder begins to practice the horizontal weld, the joint may be reclined slightly, Figure 4-63. This placement allows the welder to build the required skill by practicing the correct techniques successfully. The “J” weave or stepped pattern is suggested for this practice. As the electrode is drawn back into the weld pool, metal is deposited. This metal supports the
molten weld pool, resulting in a bead with a uniform contour, Figure 4-64.

Angling the electrode up and back toward the weld causes more metal to be deposited along the top edge of the weld. Keeping the bead small allows the surface tension to hold the molten weld pool in place.

Gradually increase the angle of the plate until it is vertical and the weld bead is horizontal.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.
PRACTICE 4-17

Outside Corner Joint in the Overhead Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-13, you will make an overhead welded outside corner joint.

- With the electrode pointed slightly into the joint, Figure 4-65, strike the arc in the joint.
- Keep a very short arc length.
- Use the stepped pattern and move the electrode forward slightly when the molten weld pool grows to the correct size, Figure 4-66.

As the molten weld pool gets larger it has a tendency to quickly become convex. If you keep the arc in the molten weld pool once the joint is filled and the weld face is flat it will quickly overfill and become convex. This can result in the weld face forming drips of metal hanging from the weld like icicles, Figure 4-67.

- When the molten weld pool cools and begins to shrink, move the arc back near the center of the weld.
- Hold the arc in this new location until the molten weld pool again grows to the correct size.
- Step the electrode forward again and keep repeating this pattern until the weld progresses along the entire weld joint length.
- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

Lap Joint

A lap joint is made by overlapping the edges of the two plates, Figure 4-68. The joint can be welded on one side or both sides with a fillet weld. In Practice 4-7, both sides should be welded unless otherwise noted.

As the fillet weld is made on the lap joint, the buildup should equal the thickness of the plate, Figure 4-69. A good weld will have a smooth transition from the plate surface to the weld. If this transition is abrupt, it can cause stresses that will weaken the joint.
Penetration for lap joints does not improve their strength; complete fusion is required. The root of fillet welds must be melted to ensure a completely fused joint. If the molten weld pool shows a notch during the weld, Figure 4-70, this is an indication that the root is not being fused together. The weave pattern will help prevent this problem, Figure 4-71.

**PRACTICE 4-18**

**Welded Lap Joint in the Flat Position (1F)**

Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, arc welding electrodes having a 1/8-in. (3-mm) diameter, and two or more pieces of mild steel plate, 6 in. (152 mm) long × 1/4 in. (6 mm) thick, you will make a welded lap joint in the flat position, Figure 4-72.

Hold the plates together tightly with an overlap of no more than 1/4 in. (6 mm). Tack weld the plates together. A small tack weld may be added in the center to prevent distortion during welding, Figure 4-73. Chip the tacks before you start to weld.

The “J,” “C,” or zigzag weave pattern works well on this joint. Strike the arc and establish a molten pool directly in the joint. Move the electrode out on the bottom plate and then onto the weld to the top edge of the
Follow the surface of the plates with the arc. Do not follow the trailing edge of the weld bead. Following the molten weld pool will not allow for good root fusion and will cause slag to collect in the root. If slag does collect, a good weld is not possible. Stop the weld and chip the slag to remove it before the weld is completed. Cool, chip, and inspect the weld for uniformity and defects. Repeat the welds with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.
PRACTICE 4-19

Welded Lap Joint in the Horizontal Position (2F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-18, you will make a welded horizontal lap joint.

The horizontal lap joint and the flat lap joint require nearly the same technique and skill to achieve a proper weld, Figure 4-75. Use the “J,” “C,” or zigzag weave pattern to make the weld. Do not allow slag to collect in the root. The fillet must be equally divided between both plates for good strength. After completing the weld, cool, chip, and inspect the weld for uniformity and defects. Repeat the welds using all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-20

Lap Joint in the Vertical Position (3F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-18, you will make a vertical up welded lap joint.

- Start practicing this weld with the plate at a 45° angle.
- Gradually increase the angle of the plate to vertical as skill is gained in welding this joint. The “J” or “T” weave pattern works well on this joint.
- Establish a molten weld pool in the root of the joint.
- Use the “T” pattern to step ahead of the molten weld pool, allowing it to cool slightly. Do not deposit metal ahead of the molten weld pool.
- As the molten weld pool size starts to decrease, move the electrode back down into the molten weld pool.
- Quickly move the electrode from side to side in the molten weld pool, filling up the joint.
- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as necessary with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-21

Lap Joint in the Overhead Position (4F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-18, you will make an overhead welded lap joint.
Chapter 4

Shielded Metal Arc Welding of Plate

93

- With the electrode pointed slightly into the joint, Figure 4-76, strike the arc in the inside corner of the lap joint.
- Keep a very short arc length.
- Use the stepped pattern and move the electrode forward slightly when the molten weld pool grows to the correct size, Figure 4-77.

As the molten weld pool gets larger it has a tendency to quickly become convex. If you keep the arc in the molten weld pool once the joint is filled and the weld face is flat it will quickly overfill and become convex. This can result in the weld face forming drips of metal hanging from the weld like icicles, Figure 4-78.
- When the molten weld pool cools and begins to shrink, move the arc back near the center of the weld.
- Hold the arc in this new location until the molten weld pool again grows to the correct size.

- Step the electrode forward again and keep repeating this pattern until the weld progresses along the entire weld joint length.
- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

Tee Joint

The tee joint is made by tack welding one piece of metal on another piece of metal at a right angle, Figure 4-79. After the joint is tack welded together, the slag is chipped from the tack welds. If the slag is not removed, it will cause a slag inclusion in the final weld.

The heat is not distributed uniformly between both plates during a tee weld. Because the plate that forms the stem of the tee can conduct heat away from the arc in only one direction, it will heat up faster than the base plate. Heat escapes into the base plate in two directions. When using a weave pattern, most of the heat should be directed to the base plate to keep the weld size more uniform and to help prevent undercut.

A welded tee joint can be strong if it is welded on both sides, even without having deep penetration, Figure 4-80. The weld will be as strong as the base plate if the size of
the two welds equals the total thickness of the base plate. The weld bead should have a flat or slightly concave appearance to ensure the greatest strength and efficiency, Figure 4-81.

**PRACTICE 4-22**

**Tee Joint in the Flat Position (1F) Using E6010 or 6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes**

Using a properly set up and adjusted arc welding machine, proper safety protection, arc welding electrodes having a 1/8-in. (3-mm) diameter, and two or more pieces of mild steel plate, 6 in. (152 mm) long × 1/4 in. (6 mm) thick, you will make a welded tee joint in the flat position, Figure 4-82.

After the plates are tack welded together, place them on the welding table so the weld will be flat. Start at one end and establish a molten weld pool on both plates. Allow the molten weld pool to flow together before starting the bead. Any of the weave patterns will work well on this joint. To prevent slag inclusions, use a slightly higher than normal amperage setting.

When the 6-in. (152-mm) -long weld is completed, cool, chip, and inspect it for uniformity and soundness. Repeat the welds as needed for all these groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.◆

**PRACTICE 4-23**

**Tee Joint in the Horizontal Position (2F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes**

Using the same setup, materials, and electrodes as listed in Practice 4-22, you will make a welded tee joint in the horizontal position.

Place the tack welded tee plates flat on the welding table so that the weld is horizontal and the plates are flat and vertical, Figure 4-83. Start the arc on the flat plate and establish a molten weld pool in the root on both plates. Using the “J” or “C” weave pattern, push the arc into the root and slightly up the vertical plate. You must keep the root of the joint fusing together with the weld metal. If the metal does not fuse, a notch will appear on the leading edge of the weld bead. Poor or incomplete root fusion will cause the weld to be weak and easily cracked under a load.

When the weld is completed, cool, chip, and inspect it for uniformity and defects. Undercut on the vertical plate is the most common defect. Repeat the welds with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.◆

**PRACTICE 4-24**

**Tee Joint in the Vertical Position (3F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes**

Using the same setup, materials, and electrodes as listed in Practice 4-22, you will make a welded tee joint in the vertical position.
Practice this weld with the plate at a 45° angle. This position will allow you to develop your skill for the vertical position. Start the arc and molten weld pool deep in the root of the joint. Build a shelf large enough to support the bead as it progresses up the joint. The square, “J,” or “C” pattern can be used, but the “T” or stepped pattern will allow deeper root penetration.

For this weld, undercut is a problem on both sides of the weld. It can be controlled by holding the arc on the side long enough for filler metal to flow down and fill it, Figure 4-84. Cool, chip, and inspect the weld for uniformity and defects. Repeat the welds as necessary with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ✦
PRACTICE 4-25

Tee Joint in the Overhead Position (4F)
Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-12, you will make a welded tee joint in the overhead position.

Start the arc and molten weld pool deep in the root of the joint. Keep a very short arc length. The stepped pattern will allow deeper root penetration.

For this weld, undercut is a problem on both sides of the weld with a high buildup in the center. It can be controlled by holding the arc on the side long enough for filler metal to flow in and fill it. Cool, chip, and inspect the weld for uniformity and defects. Repeat the welds as necessary with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean up your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor.

Summary

The shielded metal arc welding process is most often referred to in welding shops as stick welding. Some people say that it gets this name for one of two reasons. The first is most obviously as a result of the stick shape of the electrode. The second reason is experienced by all new welders; it is the tendency for the electrode to stick to the workpiece. All new welders experience this, and your ability to control the sticking of the electrode can be improved as you develop the proper arc-striking techniques.

For a new welder, it is often difficult to concentrate on anything other than the bright sparks and glow at the end of the electrode. But, with time, as you develop your skills, your visual field will increase, allowing you to see a much larger welding zone. This skill comes with time and practice. Developing this skill is essential for you to become a highly proficient welder. Nothing enhances your welding skills more than time under the hood, actually welding, cleaning off the weld, inspecting it, determining the necessary corrections to be made, and immediately trying to produce the next weld with a higher level of quality.

Keeping Shipshape through Underwater Welding

A Miami-based diving contractor helps customers avoid unscheduled drydocks by making top-quality underwater welding repairs.

Just like a bus, train, or airplane, a ship follows a time schedule. Any disruption to that schedule translates into thousands of dollars or more in lost revenue because cargo is not arriving on time or passengers cannot take their cruises. When underwater welding repairs are needed to get a vessel back on schedule, one of the companies ship owners turn to is Miami Diver, Inc.

Based in Miami, Florida, the company specializes in underwater ship maintenance, including repairs, husbandry, and surveys. Six of their twelve Miami employees are diver/welders.

Being able to work “within the ship’s schedule is actually the primary reason we’re called in,” said Kevin Peters, president of Miami Diver. That means the company’s employees travel all over the world to repair ships, and, at times, if a ship can continue underway, stay aboard and work whenever it reaches a port of call.
Miami Diver performs dry repairs using hyperbaric welding chambers and closed cofferdams, as well as wet welding repairs. The welders must work not only to the requirements of ANSI/AWS D3.6M:1999, Specification for Underwater Welding, but also to those of the various ship classification societies.

Achieving “Surface-Quality” Wet Welds

While underwater wet welding offers advantages, such as speed, versatility, and cost effectiveness, the ship classification societies consider wet welds temporary repairs, that must be redone in drydock.

AWS D3.6 divides underwater wet welds into four classes—A, B, C, and O—based on varying sets of required properties defined by mechanical tests, surface appearance, and nondestructive examination requirements. The specification defines the four classes as follows:

- **Class A** welds “are intended to be suitable for applications and design stresses comparable to their conventional surface welding counterparts by virtue of specifying comparable properties and testing requirements.”
- **Class B** welds “are intended for less critical applications where lower ductility, moderate porosity, and other limited discontinuities can be tolerated.”
- **Class C** welds “need only satisfy lesser requirements than class A, B, and O and are intended for applications where the load-bearing function is not a primary consideration.”
- **Class O** underwater welds must also meet the requirements of another code or specification.

Two years ago, in anticipation of possible changes in the American Bureau of Shipbuilding’s regulations and believing the company could provide added value to its customers by qualifying its welders to the requirements of the D3.6 standard, Peters began researching wet welding electrodes. While certain that he and the other welders could meet the B and C class requirements, Peters was not as optimistic about meeting the requirements of the all-weld-metal tensile test for A-class welds. The specification requires a minimum of 14% elongation. Less elongation can result in a lack of weld ductility.

Peters purchased quantities of each brand of underwater welding electrode. Welds were made in the training tank at the company’s Miami office, then subjected to visual and destructive testing. “In the end, we found one electrode we had never used before called Hydro-Weld FS,” Peters recalled. “We found that electrode exceeded any of our expectations as far as elongation.”

A transition to the new electrode proved somewhat difficult, however. The electrode the company had been using was equivalent to an E7014 shielded metal arc welding electrode, while the new electrode was an E6013 equivalent. “Even topside, those have different arcs,” Peters said.

The pad eyes that will hold this cofferdam to the side of the ship were welded using A-class wet welding procedures. As a result, the welds were classified as a permanent repair, which will not have to be reworked when the vessel goes into drydock. (Photo courtesy of Miami Diver, Inc.)

“When you’re accustomed to a certain rod for so long, to get [the welders] to switch was somewhat of an obstacle.”

Intensive Training

As they practiced with the new electrode, the welders found they were not getting enough penetration. Although adjustments were made following a series of phone calls between Miami and the United Kingdom, where HydroWeld is headquartered, the problem was not solved. Peters decided to bring in experts from the electrode manufacturer and conduct a training class.

Joining forces with Trident BV and Cores Diving, Peters shipped over a pallet of electrodes for the class. The companies’ goal was not only to become proficient in using the new electrode but also to become the first diving contractors in the underwater ship repair industry to offer “surface-quality, structural wet welds” that could be accepted as permanent wet welding repairs. HydroWeld wrote the wet welding procedure specifications the welders would follow and conducted the ten-day-long training program.

Involving the Classification Societies

Miami Diver brought in representatives from the six largest ship classification societies—American Bureau of Shipping, Lloyds Register of Shipping, Det Norske Veritas, Bureau Veritas, Rina, and Germanischer Lloyd—to witness the qualification of the welding procedures and welder qualifications. An independent laboratory was hired to perform tests on the weld coupons.

Three positions were used to produce the coupons: 2F horizontal, 3F vertical, and 4F overhead. Groove weld specimens for the Charpy impact and all-weld-metal tensile tests as well as a longitudinal fillet weld shear strength test specimen were produced.

In the end, the classification societies confirmed that the specimens complied with, or exceeded, the requirements of AWS D3.6M for class-A welds.
When the whole thing was over, it was probably in the neighborhood of $75,000, $80,000, to run that course [because] you have to take that many men off hire and pay the manufacturer,” Peters said. “The consumables alone were in excess of $10,000. Then [you have to pay] the class societies.”

As a result, some wet welds previously considered temporary are now deemed permanent. The customer can also avoid unscheduled drydocks, even for repairs that continue to be classified as temporary. “You can get a temporary repair that will allow the vessel to trade on its normal charter until the next scheduled drydock,” Peters said.

**Underwater Welding Jobs**

The A-class weld procedures proved useful during a recent repair job in the Indian Ocean. The vessel, a semi-submersible drill rig modified into a platform from which rockets launch satellites, is paired with a command ship. The platform’s drydock schedule is once every ten years. The owner tries to avoid unscheduled drydocks because the vessel is so large the only available drydock is in Asia. Moving the vessel there and back is extremely expensive.

A problem developed in the bow thrusters, an integral part of the platform’s dynamic positioning system that limited its ability to pitch. The only way to fix the problem was in a dry environment, so workers from Miami Diver West (the California subsidiary of Miami Diver) welded 13-ft × 13-ft cofferdams, which could be attached to the side of the ship.

Jim Allen, president of Miami Diver West, explained they built the cofferdam large enough so that, if necessary, the entire bow thruster could be disassembled, removed, and replaced with a new one. Using an enclosed cofferdam to create a dry welding environment has been done many times before, Allen said, but this one was different because they built interchangeable feet, which would allow it to meet the curvature of either the platform or the command ship. “That way we can utilize the same box for different repairs,” Allen said.

The A-class wet welding procedures were key to the repair, Allen said, because Det Norske Veritas classified the wet welds used to join the twelve pad eyes that would hold the cofferdam to the hull as permanent. Classified as permanent, the welds did not need to be reworked in drydock. Once the cofferdam was pumped dry, the pad eyes needed to hold 50 tons to the hull in a watertight seal.

“Obviously, the welds have been proven now that they’ve actually held the box under,” Peters said.

**Securing a Propulsion System**

The company also followed the A-class wet welding procedures when it performed temporary repairs on a cruise ship stuck at the Port of Miami dock.

A leak had developed in the starboard Azipod, the part of a pod propulsion system that eliminates the need for a rudder or stern thrusters, which hangs below the vessel and can rotate 360°. Because of the leak, the ship needed to go to Newport News, Virginia, to be placed into drydock for repair. While the ship could run on its own power using the port pod, any movement of the propeller blades inside the leaking pod could damage its armature and the ship’s electric motor. Time was critical because the cruise line estimated each day the ship remained off hire cost the company $1 million in lost revenue.

It was first suggested the propeller blades be removed, but no one was sure how long that would take. Miami Diver came up with what it thought was a better solution. “We told them, ‘We have wet weld procedures with Lloyds, under A class,’ ” Peters recalled. “‘We’ll make gagging plates and wet weld them to the Azipod—to the outer housing of the pod—and we’ll prevent the prop from rotating,’ ”

The A-class wet welding procedures helped sell the concept, Peters said, because the classification society had already approved those procedures. The cruise line agreed to the proposal, as did the pod manufacturer, provided the welds could pass a 50-ton load test. The manufacturer was concerned because the pod was under warranty.

“We removed two of the main fastenings to the hub and we fabricated new bolts that were studs,” Peters explained.
“This enabled us to lay a 1 1/2-in. plate over the hub of the propeller and bolt it to the propeller. Then the remaining part of the plate, approximately 1 ft, crossed over the pod housing, and it was welded with a full 1-in. by 2-ft-long fillet weld.”

The company brought in four welders from Los Angeles, welders from Holland, and part of its Miami-based crew for the project. They worked around the clock—four hours at a time in the water—to complete the job. Much of that time was spent in preparation, such as cutting plates, machining the bolts, and removing an epoxy coating from the pods.

In all, they fit and welded four gagging plates onto the housing of the Azipod. “The load test was not even an issue with us,” Peters said. “We put four plates on, but we could have held it with one plate.” Once the propeller blades could no longer move, the cruise ship successfully made its journey to Newport News.

Photos and article courtesy of the American Welding Society.

1. Describe two methods of striking an arc with an electrode.
2. Why is it important to strike the arc only in the weld joint?
3. What problems may result by using an electrode at too low a current setting?
4. What problems may result by using an electrode at too high a current setting?
5. According to Table 4-1, what would the amperage range be for the following electrodes?
   a. 1/8 in. (3.2 mm), E6010
   b. 5/32 in. (4 mm), E7018
   c. 3/32 in. (2.4 mm), E7016
   d. 1/8 in. (3.2 mm), E6011
6. What makes some spatter “hard”?
7. Why should you never change the current setting during a weld?
8. What factors should be considered when selecting an electrode size?
9. What can a welder do to control overheating of the metal pieces being welded?
10. What effect does changing the arc length have on the weld?
11. What arc problems can occur in deep or narrow weld joints?
12. Describe the difference between using a leading and a training electrode angle.
13. Can all electrodes be used with a leading angle? Why or why not?
14. What characteristics of the weld bead does the weaving of the electrode have?
15. What are some of the applications for the circular pattern in the flat position?
16. Using a pencil, draw two complete lines of the weave patterns you are most comfortable making.
17. Why is it important to find a good welding position?
18. Which electrodes would be grouped in the following F numbers: F3, F2, F4?
19. Give one advantage of using electrodes with cellulose-based fluxes.
20. What are stringer beads?
22. What effect does the root opening or root cap have on a butt joint?
23. What can happen if the fillet weld on a lap joint does not have a smooth transition?
24. Which plate heats up faster on a tee joint? Why?
25. Can a tee weld be strong if the welds on both sides do not have deep penetration? Why or why not?