Objectives
After completing this chapter, you will be able to:
❒ Identify types and grades of steel and steel alloys.
❒ Identify shapes and forms of steel and steel alloys.
❒ Select the appropriate steel filler based on the steel to be welded.
❒ Explain joint preparation, weld backing, and preheating for steels.
❒ Recall welding procedures and techniques for welding steel using DCEN.
❒ Recall correct torch positioning for various types of welds.
❒ Differentiate between stringer beads and weave beads.
❒ Recognize groove and fillet weld defects.
❒ Recall factors that influence postweld treatment.

Key Terms
annealing
casting
chromium-molybdenum steels
forging
heat treating
martensite
quenching
stringer beads
tempering
travel angle
weave beads
wetted
work angle

Introduction
The GTAW technique required for a given job depends on many factors, including the weld joint design. Welders must constantly monitor and adjust many critical variables in order to produce a high-quality weld. The effects of these variables can be seen in the behavior of the weld pool as the weld is being made. Welding skill is acquired by practice, practice, and more practice. Changing one variable at a time is the best way to determine what the weld needs.

The following questions should be considered when practicing welding:
• Is the weld the right size?
• Is the weld too high or too low?
• Is the proper travel speed being used?
• Is the torch angle correct?
• Is the welding rod being held at the proper angle?
• Is the weld pool flowing properly?
• Is the current (amperage) correct?
• Is the voltage (arc length) correct?
• Is the weld in the proper location?
• Is the fillet weld leg the proper size?

Also, it is important to remember to fill the crater at the end of the weld and hold the torch over the end of the weld until it cools. This allows the postflow of shielding gas to protect the hot metal.
Base Materials (Steel)

Many types and grades of steel are included in the steel family. These materials are typically magnetic and melt at approximately 2500°F (1371°C).

Carbon Steels

Carbon steels are identified as a group that contains the following materials:
- Carbon—1.70% maximum
- Manganese—1.65% maximum
- Silicon—0.60%

Carbon steels are further classified as low, mild, medium, and high carbon:
- Low-carbon steel—less than 20% carbon
- Medium-carbon steel—0.20%–0.50% carbon
- High-carbon steel—over 50% carbon

Low-Alloy Steels

Low-alloy steels contain varying amounts of carbon and a variety of alloying elements. These elements include chromium, molybdenum, nickel, vanadium, and manganese. These elements increase the strength and toughness of the material and, in some cases, increase resistance to corrosion.

Heat-Treated Materials

Heat-treated steels are used for many different applications. Heat treating is a process in which the material is heated and cooled to specific temperatures for specific amounts of time. A material is heat treated to obtain desirable qualities or to reduce undesirable qualities. Many materials and alloys, including aluminum, copper, titanium, nickel, and chromium-molybdenum, can be heat treated to make the material perform in different ways. Heat treating of a material is most commonly done as part of the manufacturing process.

Quenching is the process of rapidly cooling a material to obtain certain material properties that increase the material’s toughness. The quenching process changes the crystalline structure of the material. Tempering is a heat treatment that can improve the mechanical properties of a material. Tempering involves heating the metal to a certain temperature below the material’s melting temperature for a certain length of time. This process allows trapped carbon to produce a different crystalline structure. The material is then cooled at a controlled rate to a low temperature. The temperature and the duration of the tempering process determine which mechanical properties will be enhanced.

Annealing is a heat treatment that involves heating the material to a temperature that rearranges the crystalline structure and reduces internal stress of the material, making the material softer and more ductile. Annealing is typically done to improve the cold working properties of a material.

Tool Steels

Tool steels are steels with a combination of high carbon and alloy content. Tool steels are used for making dies, cutting bits, and many other types of tools. Dies and other tools are formed from annealed tool steel. Later in the manufacturing process, after the tools are formed, the metal is treated to harden or temper the metal as needed.

The various types of tool steel include W1, W2, S1, S5, S7, 01, 06, A2, A4, and D2. Also included are H11, H12, H13, and M1, M2, M10. The numbers for the various tool steels identify the various compositions. The letters usually indicate the type of quenching required to achieve full mechanical values.

Forms and Shapes of Steel

Steel is supplied in many forms and shapes for welding. Some of the more common shapes are hot-rolled steel, cold-rolled steel, castings, and forgings.

Hot-Rolled Steel

Hot-rolled steel includes plate and structural forms which are allowed to cool in air after rolling. After cooling, the oxide film on the surface is light blue in color.

Cold-Rolled Steel

This material is final-rolled to the required dimensions in the cold condition and does not have an oxide film on the surface. A light coating of oil is placed on the material to prevent rusting.

Castings

Castings refers to pouring molten metal into a mold that has the desired shape. The metal is kept in the mold until it solidifies, at which point the mold is removed. The cast metal inside has the same shape as the inside of the mold. Castings are usually made in a sand mold and have a rough surface. New castings are sandblasted, leaving a dull silver surface.

Filing Metals

Filler metals used to join carbon steels, low-alloy steels, and tool steels must be selected to produce the desired mechanical properties of the weldment after any required weld or heat treatment. Carbon and low-alloy steel filler metals are selected from specifications, such as AWS A5.28, AWS A5.38, MIL-E-23765, MIL-S-6758, and AMS6370.

When selecting a steel filler metal, the welder should consider the basic type of steel to be welded and the possibility of excessive porosity within the completed weld. Figure 8-1 lists three classifications of filler metal, each with a 70,000 psi tensile strength that can be used to weld porosity-prone material. Figure 8-2 lists several types of filler metals that can be used to weld HSLSA (high-strength, low-alloy) steels.

Chromium-molybdenum steels (chrome-moly steels) are a class of extremely strong and hard steels. If the chrome-moly weldment is to be hardened after being welded, one of the following filler metals should be used:
- 1-1/4% chrome—1% moly filler metal
- 2-1/4% chrome—1% moly filler metal
- 4%–6% chrome (AISI 502)

Forgings

Forging refers to pressing a shaped die into hot metal, under high pressure. The metal is heated to a plastic state before it is forged so it will take on the shape of the die that is pressed into it. Forgings are made from billets, bars, round stock, or square stock. Forgings can be identified by the remnants of the flashing usually extending around the center of the part. Since the forging operation is done while the part is hot, a scale forms on the surface, similar to the scale on hot-rolled steel.

Steel Classifications

Steels are manufactured to specifications developed by various organizations, including ASTM International. One grouping of steels under this classification is ASTM A335. The assigned designation identifies the material as high-ferritic steel alloy pipe for high-temperature applications. Other steel specifications include SAE International’s Aerospace Material Specifications (AMS), the American Iron and Steel Institute (AISI) classifications, and corporation specifications.

Filler Metal Quality

Steel filler metals are supplied by the manufacturer with a bright finish, oiled finish, or copper flash finish. Since these materials are susceptible to rusting, store them in a dry, heated area until they are needed. Always clean the filler metal with acetone or alcohol just before use. Return all unused material to the storage area.
Joint Preparation

Joint edges prepared by thermal cutting processes have a heavy oxide film on the surface, as shown in Figure 8-3. This oxide should be completely removed prior to welding in order to prevent porosity in the weld metal.

Joint edges prepared by shearing should be sharp without tearing or ridges. Otherwise, dirt or oil can become trapped in the joint and result in faulty welds. Rough edges can be removed prior to welding with a light grinding.

Weld Backing for Steel

Groove welds that are welded from one side of the joint, where 100% penetration is required, can be backed with argon gas or a solid bar. Solid bars can be made of copper or stainless steel.

Excluding air from the backside or penetration side of the joint will assist in wetting of the penetration. A wetted penetration has a smooth junction and even flow of the penetration onto the base metal. The exclusion of air also prevents the formation of scale and oxide.

Preheating Steels

Carbon steels less than 1” (25.4 mm) thick and with less than 30% carbon generally do not require preheat. Welding on highly restrained joints is an exception. These joints should be preheated to 50°–100°F (10°–38°C) to minimize shrinkage cracks in the base metal and the weld deposit.

Low-alloy steels, such as the chrome-moly steels, have hard heat-affected zones after welding if the preheat temperature is too low. The hard heat-affected zones are caused by the rapid cooling rate of the base material and the formation of martensitic grain structures. A 200°–400°F (93°–204°C) preheat temperature slows down the cooling rate and prevents the formation of a martensitic structure.

Martensite is a metallurgical term that defines a type of grain structure obtained by heating and quenching. The martensitic grain structure makes the metal hard. Parts that are welded are, in effect, heated and quenched. If the carbon content of the material is sufficient, and the preheat temperature is too low, the material in the heat-affected zone will harden during welding. This results in high tensile properties with very low ductility. The formation of hard martensite-type grains increases the possibility of cracking as the weld metal cools and shrinks.

Torch Angles and Bead Placement

Proper manipulation of the welding torch is very important in making a good weld. The torch is usually held like a pencil, as shown in Figure 8-5. When welding is done in the flat position, the hand should be placed lightly on a surface, so the hand can be moved in any direction as required.
move across the joint evenly. Movement of the torch by the fingers alone usually results in incorrect torch angles and a poor weld.

Torch angles are very important to maintain and understand. The torch angles control the heat of the arc, and the weld pool will move where it is directed by the torch angles. Two different torch angles, the work angle and the travel angle, greatly affect how the weld bead is placed into the weld joint.

The work angle is the angle of the torch in a plane that is perpendicular to the weld axis and is measured from the perpendicular position to the torch’s actual position. See Figure 8-6A. Work angles usually split the weld pool evenly between the two pieces of base metal. When the work angle points to one side of the joint more than the other, the weld will move in that direction. For example, on a flat butt joint, the work angle is 90°, straight up and down into the joint. Work angles are generally straight into the middle of the joint. The weld pool will show if the weld is favoring one side or the other. When this happens, the welder must adjust the work angle to correct the uneven weld.

The travel angle is the angle of the torch in the plane parallel to the weld axis and is measured from the perpendicular position to the torch’s actual position. See Figure 8-6B. The torch should always be pushed in the direction of the weld. Torch travel angles are usually 15° to 20°. The main reason to maintain a good travel angle is so that the welder can see the weld pool. The welder must be able to see the weld pool when making any weld. The actual weld pool is much smaller than the ceramic cup on the end of the torch, so the torch must be laid over so the weld pool can be seen. However, travel angles that are too severe can suck air into the weld from the back side, causing porosity or other discontinuities due to atmospheric contamination.

For welding butt joints in any position, the suggested work angle is generally 90°. Because the work angle is perpendicular to the workpiece, it provides maximum penetration. The suggested travel angle for welding butt joints is typically a push angle of 15°–20°. The term push angle refers to the torch being pointed in the direction the weld progresses. This angle allows the welder to see the weld pool, but still provides good penetration. A larger travel angle would create an elongated weld pool and decrease the penetration into the joint. The welding rod is typically held 10°–20° from the surface of the base metal. This angle makes it easy for the welder to see the weld pool and to feed welding rod into the weld pool as needed. See Figure 8-7.

When making fillet welds, the torch is generally held at a 45° work angle and a 15°–20° travel angle. If an inside corner joint is being welded, the tip of the electrode is pointed directly at the joint between the two workpieces. If a lap joint is being welded, the tip of the electrode should be pointed slightly more toward the surface piece than the edge piece. The edges of a metal plate are not able to dissipate heat as quickly as the large surfaces of the plate. As a result, if the torch is pointed directly at the joint between the two plates, the edge of one piece heats up faster than the surface of the other, which can lead to undercutting at the edges of the joint. Pointing the torch slightly more toward the surface than the edge provides even heating through the entire joint. See Figure 8-8.

When adding welding rod, the welder should grip the rod in the fingers as shown in Figure 8-9. The hand should be kept as close as possible to the arc to hold the rod steady. The rod should be moved in conjunction with the torch movement. When additional rod is required, it can be moved forward through the fingers using a forward movement of the thumb. Too much extension of the welding rod from the fingers results in a wobbly rod end, making addition to the weld pool very uneven. Adding rod to the pool requires steadiness and concentration in order to place the correct...
Welding Steels Using DCEN (Straight) Polarity

DCEN polarity is used for welding steels because the higher concentration of heat input into the base material results in deeper penetration. DCEN polarity is the best option for obtaining full penetration welds and controllable weld bead profiles. With DCEN polarity, two-thirds of the arc’s heat is concentrated on the workpiece and one-third is concentrated on the electrode. Since the majority of the heat is concentrated on the work and not on the electrode, smaller electrodes can be used without worrying about electrode deterioration.

Electrodes Used on Steels

For a long time, 1% or 2% thoriated electrodes were recommended for welding steel. When thorium is added to tungsten in small amounts, it increases the electrode’s current-carrying capabilities. Thoriated electrodes do not work well with ac current and are not recommended for use with the newer inverter-type machines. If thoriated electrodes are overheated, the end of the electrode can begin to vaporize and spit small amounts of the electrode into the weld. Grinding thoriated tungsten electrodes results in radioactive dust that can be hazardous. These electrodes usually have a yellow or red color band near the top of the electrode, depending on the percentage of thorium.

Today, electrodes with more desirable characteristics are available. Lanthanated tungsten electrodes are relatively new to the US, but are becoming more popular. Lanthanum is a “rare earth” material that is not radioactive. Lanthanated electrodes work well for ac or dc currents, have good current-carrying capacities, and can be used universally, eliminating the confusion of selecting an electrode. Lanthanated electrodes usually have a black color band near the top of the electrode.

Other types of electrodes, such as ceriated, zirconiated, and pure tungsten, all have some desirable traits. Ceriated tungsten usually have an orange color band, zirconiated tungsten usually have a brown color band, and pure tungsten usually have a green color band. Research the base materials to be welded to determine which electrode is best suited for your application. More detailed information about different electrode types and when they should be used was presented in Chapter 3, Auxiliary Equipment and Systems.

Amperage ranges must be considered when selecting the size of the electrode. Higher welding amperages require larger electrodes.

Shielding Gases for GTAW on Steels

Pure argon gas can be used when welding metal up to 1/8” (3.2 mm) thick. When thicker materials are being welded, helium should be added to the shielding gas to improve weld pool control and penetration. Helium increases the temperature of the arc, resulting in deeper penetration. The following standard shielding gas mixes can be used:

- 75% argon–25% helium
- 50% argon–50% helium
- 25% argon–75% helium

Pure helium gas can be used for automatic welding of steel or steel alloys. Gas purity must be sufficient to prevent hydrogen pickup. Hydrogen will cause porosity and cracking.

Techniques for Welding Steels and Steel Alloys

1. Clean the oxide scale from the weld joint immediately prior to welding. Clean the entire weld area to bright metal.
2. Select a welding rod that has the required properties. When welding porosity-prone material, always use a welding rod that contains deoxidizers to prevent porosity.
3. Preheat low-alloy steels and tool steels to prevent cracking in the weld and heat-affected zones.
4. Weld porosity-prone materials by maintaining the arc on the molten metal. Do not hold the arc on the base metal. On crack-sensitive materials, do not make concave welds. These welds are prone to cracking through the centerline.
5. On multipass welds, always remove any scale on the arc entrance angle of the rod into the weld pool should always be maintained.

amount of material at the right place at exactly the right time. A 10°–20° entrance angle of the rod into the weld pool should always be maintained.

Types of Beads/Passes

Welds made without any side-to-side movement (oscillation) of the torch are called stringer beads or stringer passes. Welds made with side-to-side movement of the torch are called weave beads. When a weave bead is being made, filler metal should be added at the edges of the weld pool to prevent undercutting. Figure 8-10 compares a stringer bead and a weave bead. A technique known as walking, or rocking, the cup is commonly used to create a weave pattern in V-groove butt joints in thicker sections of material. In this oscillation technique, the cup of the torch is actually set on the base metal and rocked back and forth, much like moving a refrigerator across the floor. Walking or rocking the cup to make a weave pattern takes a great deal of practice and determination.
The following eleven procedures have been developed for GTAW practice and production. Any scrap material can be used for practice. Clean all of the materials, as previously discussed, before tack welding and welding.

When steel is being welded, a small white dot may form on the weld pool surface. This is a normal condition and does not require any corrective action. The material in the dot is silicon, which separates from the base material and the welding rod. It floats on the surface because it is lighter than the metal.

Gas nozzle sizes are not specified, since many variables are involved. Always use the largest possible size. However, do not use a size that will obstruct your view of the weld pool.

Tooling can be used when welding practice plates. Tools assist in holding the material in the proper plane and prevent warpage and misalignment during the welding sequence. The tooling may also have a gas manifold to permit use of a backing gas, if desired. See Figure 8-11.

1. Welding Procedure Number 8-1

   **Weld joint type:** Flat plate autogenous weld  
   **Position:** Flat  
   **Material type:** Cold-rolled steel  
   **Thickness:** 1/16” (1.6 mm)  
   **Machine setup:** DCEN high-frequency start  
   **Shielding gas:** Argon  
   **CFH:** 15–25  
   **Tungsten type:** 1%, 1.5%, or 2% lanthanated, ceriated, or thoriated  
   **Diameter:** 1/16” (1.6 mm) (tapered)

   **Procedure:**
   1. Prepare and clean the materials.  
   2. Raise the part to be welded 1/8” (3.2 mm) above the table with metal blocks.  
   3. Align the torch to the angles shown in Figure 8-12 (90° work angle and 15°–25° travel angle) and lower the torch until the tip of the electrode is approximately 1/8” (3.2 mm) from the top surface.  
   4. Start the arc at low current; lower the torch until the electrode tip is approximately 1/16” (1.6 mm) from the surface.
   5. Increase the amperage and form a weld pool approximately 3/16” (4.8 mm) in diameter.  
   6. Move the torch forward while:
      A. Maintaining the weld pool size.  
      B. Maintaining the torch height.  
      C. Maintaining the torch angles.  
   7. Stop the weld at the end of the plate.
      A. Do not lift the torch away from the plate. Postflow gas will protect the hot metal during the cooling period.

   **Problem Areas and Corrections**
   1. Uneven top weld width and depression.  
      **Possible cause:** Variation in welding speed.  
      **Solution:** Maintain a consistent travel speed.
   2. Uneven contour.  
      **Possible cause:** Incorrect torch angle.  
      **Solution:** Align the torch vertically over the weld.
   3. Uneven penetration or lack of penetration.  
      **Possible cause:** Insufficient amperage.  
      **Solution:** Increase amperage.

2. Welding Procedure Number 8-2

   **Weld joint type:** Bead on plate  
   **Position:** Flat  
   **Material type:** Cold-rolled steel  
   **Thickness:** 1/16” (1.6 mm)  
   **Filler metal:** ER70S-2 or 6  
   **Diameter:** .045” (1.1 mm)  
   **Machine setup:** DCEN high-frequency start  
   **Shielding gas:** Argon  
   **CFH:** 15–25  
   **Tungsten type:** 1%, 1.5%, or 2% lanthanated, ceriated, or thoriated  
   **Diameter:** 1/16” (1.6 mm) (tapered)

   **Procedure:**
   1. Prepare and clean the materials.  
   2. Raise the part to be welded 1/8” (3.2 mm) above the table with metal blocks.  
   3. Align the torch to the angles shown in Figure 8-12 and lower the torch until the tip of the electrode is approximately 1/8” (3.2 mm) from the top surface.
   4. Start the arc at low current; lower the torch until the electrode tip is approximately 1/16” (1.6 mm) from the surface.
   5. Increase the amperage and form a weld pool approximately 3/16” (4.8 mm) in diameter.  
   6. Move the torch forward while:
      A. Maintaining the weld pool size.  
      B. Maintaining the torch height.  
      C. Maintaining the torch angles.  
   7. Stop the weld at the end of the plate.
      A. Do not lift the torch away from the plate. Postflow gas will protect the hot metal during the cooling period.

   **Problem Areas and Corrections**
   1. Uneven top weld width and depression.  
      **Possible cause:** Variation in welding speed.  
      **Solution:** Maintain a consistent travel speed.
   2. Uneven contour.  
      **Possible cause:** Incorrect torch angle.  
      **Solution:** Align the torch vertically over the weld.
   3. Uneven penetration or lack of penetration.  
      **Possible cause:** Insufficient amperage.  
      **Solution:** Increase amperage.

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Figure 8-11. Tooling can support the weld and provide backing gas. A—Hand-built copper backing plates for providing cover gas to the back side of a butt weld. The weld is positioned on top of the plate and welded. B—This fixture includes a manifold for backing gas. The weldment is clamped and held in place by the top bars. (Mark Prosser)

Figure 8-12. Torch position for an autogenous weld in the flat position. (Mark Prosser)

Figure 8-13. Torch and welding rod positions for running a bead on a plate in the flat position. (Mark Prosser)
4. Hold the welding rod as shown in Figure 8-13 and move it so the end is approximately 1/16" (25.4 mm) from the electrode.

5. Start the arc at low current. Lower the torch so the electrode tip is approximately 1/16" (1.6 mm) from the surface.

6. Increase the amperage and form a weld pool approximately 1/4" (6.5 mm) in diameter.

7. Bring the rod into the front edge of the pool and melt enough rod to form a slight crown on the surface.

8. Draw the rod approximately 1/2" (12.7 mm) away from the pool.

9. Move the torch forward approximately 3/16" (4.8 mm) and add rod again as in Step 7.

10. Continue moving the arc across the joint, adding rod as before.

11. Stop the weld at the end of the plate. Remember to hold the torch at the end until the weld cools. This protects the weld with shielding gas as it cools.

**Problem Areas and Corrections:**

1. Uneven top weld width and low crown.
   - **Possible cause:** Variation in travel speed.
   - **Solution:** Maintain a consistent travel speed.

   1. **Solution:** Heat buildup in the weld pool.
   - **Solution:** Increase the travel speed as the plate gets hotter.

   2. **Possible cause:** Heat buildup in the weld pool.
   - **Solution:** Add rod to form a consistent crown.

   2. **Possible cause:** Torch not aligned vertically.
   - **Solution:** Maintain a 90° work angle.

   3. **Possible cause:** Not enough filler metal added to the weld pool.
   - **Solution:** Increase amperage and add more welding rod.

   4. **Possible cause:** Inconsistent travel speed.
   - **Solution:** Increase amperage and add more filler metal.

   5. **Possible cause:** Inconsistent torch height.
   - **Solution:** Hold the torch at a consistent height.

   6. **Possible cause:** Inconsistent rod addition.
   - **Solution:** Add filler metal to create a consistent crown on the weld pool.

   7. **Possible cause:** Insufficient amperage.
   - **Solution:** Increase amperage and add more filler metal.

   8. **Possible cause:** Inconsistent torch height.
   - **Solution:** Maintain a consistent torch height.

   9. **Possible cause:** Improper torch position or angle.
   - **Solution:** Maintain the proper torch angles and position the torch on the centerline of the joint.

**Welding Procedure Number 8-3**

- **Weld joint type:** Square-groove butt
- **Position:** Flat
- **Material type:** Cold-rolled steel
- **Thickness:** 1/16" (1.6 mm)
- **Filler metal:** ER70S-2 or 6
- **Diameter:** .045"–.062" (1.1 mm – 1.6 mm)
- **Machine setup:** DCEN high-frequency start
- **Shielding gas:** Argon
- **CFH:** 15–25
- **Tungsten type:** 1%, 1.5%, or 2% lanthanated, ceriated, or thoriated
- **Diameter:** 1/16" (1.6 mm) (tapered)

**Procedure:**

1. Prepare and clean the materials.
2. Tack weld the plates together.
3. Raise the part to be welded 1/8" (3.2 mm) above the table with metal blocks.
4. Align the torch to the angles shown in Figure 8-14 and lower the torch until the electrode tip is approximately 1/8" (3.2 mm) from the surface.
5. Position the end of the welding rod approximately 1" (25.4 mm) from the electrode.
6. Start the arc at low current. Lower the torch until the electrode tip is approximately 1/16" (1.6 mm) from the surface.
7. Increase the amperage and form a weld pool approximately 1/4" (6.5 mm) in diameter.
8. Bring the rod into the front edge of the pool and melt enough rod to form a slight crown on the surface.
9. Draw the rod approximately 1/2" (12.7 mm) away from the weld pool.
10. Move the torch forward approximately 3/32" (2.4 mm) and add rod again as in Step 8.
11. Continue moving the torch across the joint, adding rod as before.
   - A. Maintain the proper torch angles.
   - B. Keep the electrode on the centerline of the joint.

12. Stop the weld at the end of the plate. Be sure to fill the crater completely. Remember to hold the torch at the end until the weld cools.

**Problem Areas and Corrections:**

1. Uneven top weld width and low crown.
   - **Possible cause:** Variation in travel speed.
   - **Solution:** Maintain a consistent travel speed.

   1. **Solution:** Heat buildup in the weld pool.
   - **Solution:** Increase the travel speed as the plate gets hotter.

   2. **Possible cause:** Heat buildup in the weld pool.
   - **Solution:** Add rod to form a consistent crown.

   2. **Possible cause:** Torch not aligned vertically.
   - **Solution:** Maintain a 90° work angle.

   3. **Possible cause:** Not enough filler metal added to the weld pool.
   - **Solution:** Increase amperage and add more welding rod.

   4. **Possible cause:** Inconsistent travel speed.
   - **Solution:** Increase amperage and add more filler metal.

   5. **Possible cause:** Inconsistent torch height.
   - **Solution:** Hold the torch at a consistent height.

**Welding Procedure Number 8-4**

- **Weld joint type:** Square-groove butt
- **Position:** Horizontal
- **Material type:** Cold-rolled steel
- **Thickness:** 1/16" (1.6 mm)
- **Filler metal:** ER70S-2 or 6
- **Diameter:** .045"–.062" (1.1 mm – 1.6 mm)
- **Machine setup:** DCEN
- **Shielding gas:** Argon
- **CFH:** 15–25
- **Tungsten type:** 1%, 1.5%, or 2% lanthanated, ceriated, or thoriated
- **Diameter:** 1/16" (1.6 mm) (tapered)

**Procedure:**

1. Prepare and clean the materials.
2. Tack weld the plates together.
3. Align the parts to be welded with the joint in the horizontal position.
4. Align the torch to the angles shown in Figure 8-15 and move the torch toward the joint until the tip of the electrode is approximately 1/8" (3.2 mm) from the surface.
5. Hold the welding rod as shown in Figure 8-15 and position it so the end is approximately 1" (25.4 mm) from the surface.
6. Start the arc at low current. Move the torch toward the joint until the tip of the electrode is approximately 1/16" (1.6 mm) from the surface.
7. Increase the amperage and form a weld pool approximately 3/32" (2.4 mm) and add rod again as in Step 6.
8. Increase the amperage to form a weld pool approximately 1/16" (1.6 mm) from the surface.
9. Bring the rod into the front edge of the pool and melt enough rod to form a slight crown.
10. Move the torch forward approximately 3/32" (2.4 mm) and add rod again as in Step 6.
11. Continue moving the torch across the joint, adding rod as before.
   - A. Maintain the proper torch angles.
   - B. Keep the electrode on the centerline of the joint.

12. Stop the weld at the end of the plate. Be sure to fill the crater completely. Remember to hold the torch at the end until the weld cools.

**Problem Areas and Corrections:**

1. Uneven top weld width and low crown.
   - **Possible cause:** Variation in travel speed.
   - **Solution:** Maintain a consistent travel speed.

   1. **Solution:** Heat buildup in the weld pool.
   - **Solution:** Increase the travel speed as the plates get hotter.

   2. **Possible cause:** Heat buildup in the weld pool.
   - **Solution:** Add rod to form a consistent crown.

   2. **Possible cause:** Torch not aligned vertically.
   - **Solution:** Maintain a 90° work angle.

   3. **Possible cause:** Not enough filler metal added to the weld pool.
   - **Solution:** Increase amperage and add more welding rod.

   4. **Possible cause:** Inconsistent travel speed.
   - **Solution:** Increase amperage and add more filler metal.

   5. **Possible cause:** Inconsistent torch height.
   - **Solution:** Hold the torch at a consistent height.

**Figure 8-14. Torch position for a square-groove butt weld in the flat position. (Mark Prosser)**

**Figure 8-15. Torch and welding rod positions for a square-groove butt weld in the horizontal position. (Mark Prosser)**
Welding Procedure Number 8-5

Weld joint type: Square-groove butt
Position: Vertical upright
Material type: Cold-rolled steel
Thickness: 1/16" (1.6 mm)
Filler metal: ER70S-2 or 6
Diameter: .045"–.062" (1.1 mm – 1.6 mm)
Machine setup: DCEN high-frequency start
Shielding gas: Argon
CFH: 15–25
Tungsten type: 1%, 1.5%, or 2% lanthanated, ceriated, or thoriated
Diameter: 1/16" (1.6 mm) (tapered)

Procedure:
1. Prepare and clean the materials.
2. Tack weld the plates together.
3. Align the parts to be welded with the joint in the vertical position.
4. Align the torch to the angles shown in Figure 8-16 and move the torch toward the joint until the tip of the electrode is approximately 1/8" (3.2 mm) from the surface.
5. Hold the welding rod so the end is approximately 1" (25.4 mm) from the electrode.
6. Start the arc at low current. Move the torch toward the joint until the tip of the electrode is approximately 1/16" (1.6 mm) from the surface.
7. Increase the amperage to form a weld pool approximately 3/16" (4.8 mm) in diameter.
8. Bring the welding rod into the upper part of the pool and melt enough filler metal to form a slight crown on the surface.
9. Draw the welding rod approximately 1/2" (12.7 mm) away from the weld pool.
10. Move the torch upward approximately 3/32" (2.4 mm) and add welding rod again as in Step 8.
11. Continue moving upward, adding welding rod as before.
12. Stop the weld at the end of the plate. Remember to hold the torch at the end until the weld cools.

Problem Areas and Corrections:
1. Undercut at top of weld crown.
   Possible cause: Torch angle flat.
   Solution: Add welding rod to the top of the weld pool.
   Possible cause: Gravity.
   Solution: Add welding rod to the top of the weld pool.
3. Penetration is uneven on the centerline of the weld.
   Possible cause: Torch not centered on the joint.
   Solution: Keep the electrode centered on the joint.

Problem Areas and Corrections:
1. Undercut.
   Possible cause: Insufficient amount of filler metal added.
   Solution: Add rod in the top and center of the weld pool.
2. High crown.
   Possible cause: Too much filler metal added to weld pool.
   Solution: Add filler metal in smaller amounts.
3. Uneven penetration or lack of penetration.
   Possible cause: Inconsistent travel speed.
   Solution: Maintain a consistent travel speed.
4. Inconsistent filler metal addition.
   Possible cause: Inconsistent filler metal addition.
   Solution: Add filler metal to maintain a consistent crown on the weld pool.
5. Incorrect torch angles.
   Possible cause: Heat buildup in the weld pool.
   Solution: Increase travel speed as the plates get hotter.

Welding Procedure Number 8-6

Weld joint type: Square-groove butt
Position: Flat
Material type: Cold-rolled steel
Thickness: 11 gauge
Filler metal: ER70S-2 or 6
Diameter: 3/32" (2.4 mm) or 1/8" (3.2 mm) (welder’s preference)
Machine setup: DCEN high-frequency start
Shielding gas: Argon
CFH: 15–25
Tungsten type: 1%, 1.5%, or 2% lanthanated, ceriated, or thoriated
Diameter: 3/32" (2.4 mm) (tapered)

Procedure:
1. Prepare and clean the materials.
2. Tack weld the plates with 3/32" (2.4 mm) or 1/8" (3.2 mm) spacing, depending on the filler being used. Mount the joint approximately 1/8" (3.2 mm) above the table with metal blocks.
3. Weld the root pass to ensure full penetration.
   a. Maintain the torch on the weld pool with the proper angles. Use the same work and travel angles shown in Figure 8-14.

Problem Areas and Corrections:
1. Undercut.
   Possible cause: Insufficient filler metal added to the weld pool.
   Solution: Add welding rod to the edge of the weld pool on the crown pass.
   Possible cause: Inconsistent travel speed.
   Solution: Maintain a consistent travel speed.
3. Uneven penetration.
   Possible cause: Inconsistent filler metal addition.
   Solution: Add filler metal to create a consistently sized crown.
4. Uneven penetration.
   Possible cause: Inconsistent travel speed.
   Solution: Maintain a consistent travel speed.

Welding Procedure Number 8-7

Weld joint type: Square-groove butt
Position: Horizontal
Material type: Cold-rolled steel
Thickness: 11 gauge
Filler metal: ER70S-2 or 6
Diameter: 3/32" (2.4 mm) or 1/8" (3.2 mm) (welder’s preference)
Machine setup: DCEN
Shielding gas: Argon
CFH: 10–15
Tungsten type: 2% thoriated
Diameter: 3/32" (2.4 mm) (tapered)
**Procedures:**

1. Prepare and clean the materials.
2. Tack weld the plates with 3/32" (2.4 mm) or 1/8" (3.2 mm) spacing, depending on the filler metal used. Mount the joint in the horizontal position.
3. Weld the root pass with 3/32" (2.4 mm) or 1/8" (3.2 mm) diameter welding rod.
   A. Add the welding rod to the top of the weld pool. Use the work and travel angles shown in Figure 8-15.
   B. Add the welding rod directly to the pool (welder’s preference).
4. Wire brush the weld to remove the oxide film (both passes).
5. Realign the torch and weld a second pass. Use a 3/32" (2.4 mm) or 1/8" (3.2 mm) diameter welding rod.
   A. Do not oscillate the torch. The weld should be approximately 1/16" (1.6 mm) wider than the groove, and the weld crown should not be over 1/16" (1.6 mm) high.

**Problem Areas and Corrections:**

1. Undercut.
   **Possible cause:** Sagging due to gravity.
   **Solution:** Add welding rod at the top of the weld pool.
   **Possible cause:** Weld bead is excessively large.
   **Solution:** Hold the torch and welding rod at the proper angles.
2. Uneven bead width.
   **Possible cause:** Variation in the size and shape of the weld pool.
   **Solution:** Determine the size of each pass before starting.
3. Concave weld crown.
   **Possible cause:** Excessive amperage.
   **Solution:** Use a lower amperage range and add filler metal more often.

**Welding Procedure Number 8-8**

<table>
<thead>
<tr>
<th>Weld joint type</th>
<th>Square-groove butt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>Vertical uphill</td>
</tr>
<tr>
<td>Material type</td>
<td>Cold-rolled steel</td>
</tr>
<tr>
<td>Thickness</td>
<td>11 gauge</td>
</tr>
<tr>
<td>Filler metal</td>
<td>ER70S-6</td>
</tr>
<tr>
<td>Diameter</td>
<td>3/32&quot; (2.4 mm) or 1/8&quot; (3.2 mm)</td>
</tr>
<tr>
<td>Machine setup</td>
<td>DCEN high-frequency start</td>
</tr>
<tr>
<td>Shielding gas</td>
<td>Argon</td>
</tr>
<tr>
<td>CFH</td>
<td>15–25</td>
</tr>
<tr>
<td>Tungsten type</td>
<td>1%, 1.5%, or 2% lanthanated, ceriated, or thoriated</td>
</tr>
<tr>
<td>Diameter</td>
<td>3/32&quot; (2.4 mm) (tapered)</td>
</tr>
</tbody>
</table>

**Procedure:**

1. Prepare and clean the materials.
2. Tack weld the plates with 3/32" (2.4 mm) or 1/8" (3.2 mm) spacing depending on the filler metal used. Mount the joint in the vertical position.
3. Weld the root pass with 3/32" (2.4 mm) or 1/8" (3.2 mm) diameter welding rod. Use the same travel and work angles shown in Figure 8-16.
   A. Add the welding rod to the top of the weld pool.
   B. Add the welding rod directly to the pool (welder’s preference).
   C. Keep the electrode centered over the molten pool.
4. Wire brush the weld to remove the oxide film (all passes).
5. Realign the torch and weld the second pass using a 3/32" (2.4 mm) or 1/8" (3.2 mm) diameter welding rod.
   A. Use a slight oscillation for a wider bead.
   B. Add welding rod at the edge of the weld pool and always wait for a moment before dipping the filler into the weld pool. Keep the weld pool in a fluid state.

**Problem Areas and Corrections:**

1. Undercut.
   **Possible cause:** Sagging due to gravity.
   **Solution:** Add welding rod at the top of the weld pool.
   **Possible cause:** Weld bead is excessively large.
   **Solution:** Hold the torch and welding rod at the proper angles.
2. Irregular crown height or width.
   **Possible cause:** Improper feeding of welding rod.
   **Solution:** Feed welding rod into the weld pool often, and in small quantities.

**Welding Procedure Number 8-9**

<table>
<thead>
<tr>
<th>Weld joint type</th>
<th>T-joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Material type</td>
<td>Cold-rolled steel</td>
</tr>
<tr>
<td>Thickness</td>
<td>1/16&quot; (1.6 mm)</td>
</tr>
<tr>
<td>Filler metal</td>
<td>ER70S-2 or 6 (welder’s preference)</td>
</tr>
<tr>
<td>Diameter</td>
<td>.045&quot; – .062&quot; (1.1 mm – 1.6 mm)</td>
</tr>
<tr>
<td>Machine setup</td>
<td>DCEN high-frequency start</td>
</tr>
<tr>
<td>Shielding gas</td>
<td>Argon</td>
</tr>
<tr>
<td>CFH</td>
<td>15–25</td>
</tr>
<tr>
<td>Tungsten type</td>
<td>1%, 1.5%, or 2% lanthanated, ceriated, or thoriated</td>
</tr>
<tr>
<td>Diameter</td>
<td>1/16&quot; (1.6 mm) (tapered)</td>
</tr>
</tbody>
</table>

**Procedure:**

1. Prepare and clean the materials.
2. Align the plates.
3. Tack weld the two plates at approximately right angles.
4. Weld the joint using the torch and welding rod angles shown in Figure 8-17.
   A. Add the welding rod often and in small amounts.
   B. The filler metal will flow evenly to both pieces and the crown should be flat to slightly convex.
   C. Feed the welding rod directly into the intersection of the joint.

**Problem Areas and Corrections:**

1. Concave weld crown.
   **Possible cause:** Too large a welding rod size causing irregular heating of the weld pool.
   **Solution:** Use a smaller welding rod.
2. Crooked or uneven beads.
   **Possible cause:** Variation in the size and shape of the weld pool.
   **Solution:** Determine the size of each pass before starting.
3. Concave root surface or melt-through.
   **Possible cause:** Weld pool is too hot.
   **Solution:** Use a smaller diameter welding rod and add it often to control pool temperature.
   **Solution:** Lower the amperage setting.

**Welding Procedure Number 8-10**

<table>
<thead>
<tr>
<th>Weld joint type</th>
<th>T-joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Material type</td>
<td>Cold-rolled steel</td>
</tr>
<tr>
<td>Thickness</td>
<td>11 gauge</td>
</tr>
<tr>
<td>Filler metal</td>
<td>ER70S or 6 or 2 or 4 (welder’s preference)</td>
</tr>
<tr>
<td>Diameter</td>
<td>3/32&quot; (2.4 mm) or 1/8&quot; (3.2 mm)</td>
</tr>
<tr>
<td>Machine setup</td>
<td>DCEN high-frequency start</td>
</tr>
<tr>
<td>Shielding gas</td>
<td>Argon</td>
</tr>
<tr>
<td>CFH</td>
<td>15–25</td>
</tr>
<tr>
<td>Tungsten type</td>
<td>1%, 1.5%, or 2% lanthanated, ceriated, or thoriated</td>
</tr>
<tr>
<td>Diameter</td>
<td>3/32&quot; (2.4 mm) (tapered)</td>
</tr>
</tbody>
</table>

**Procedure:**

1. Prepare and clean the materials.
2. Align the plates.
3. Tack weld the two plates at approximately right angles.
4. Weld the root pass using the torch and welding rod angles shown in Figure 8-17.
   A. Add filler metal in small amounts.
   B. Feed the welding rod directly into the intersection of the joint for the root pass.

**Possible cause:** Too large a welding rod size causing irregular heating of the weld pool.
**Solution:** Use a smaller welding rod.
Welding Procedure Number 8-11

Weld joint type: T-joint
Position: Vertical uphill
Material type: Cold-rolled steel
Thickness: 11 gauge
Filler metal: ER70S-2 or 6
Diameter: 3/32” (2.4 mm) or 1/8” (3.2 mm) (welder’s preference)
Machine setup: DCEN high-frequency start
Shielding gas: Argon
CPH: 15–25
Tungsten type: 1%, 1.5%, or 2% lanthanated, ceriated, or thoriated
Diameter: 3/32” (2.4 mm) (tapered)

Procedure:
1. Prepare and clean the materials.
2. Align the plates.
3. Tack weld the two plates at approximately right angles.
4. Weld the joint using the torch and welding rod angles shown in Figure 8-19.
   A. Add the filler metal in small amounts.
   B. Feed the welding rod directly into the intersection of the joint.
   C. Wire brush the joint to remove the oxide film.

Problem Areas and Corrections:
1. Concave weld crown or improper contour.
   Possible cause: Insufficient filler metal.
   Solution: Add welding rod more often.
   Possible cause: Incorrect torch angle and improperly placed welds.
   Solution: Increase the travel speed.
2. Leg sizes are not equal.
   Possible cause: Incorrect torch angle.
   Solution: Reposition the torch to keep the weld pool even.
   Possible cause: Too much filler metal. Weld pool is too heavy.
   Solution: Add less filler metal.
3. Undercut on top weld.
   Possible cause: Weld pool is too hot.
   Solution: Add welding rod more often.
   Possible cause: Incorrect torch angle.
   Solution: Reposition the torch to keep the weld pool even.

Reading the Weld Pool

The ability to read a weld pool is a very important skill for welders, particularly in GTAW because the weld pool is relatively small. This skill develops with practice and an increased understanding of the variables that affect the weld. By reading the weld pool, a welder can tell when the travel speed is too fast or too slow and when torch angles are incorrect. The weld pool reveals discontinuities as they happen. Reading the weld pool enables the welder to make “on-the-fly” adjustments to ensure a quality weld.

Groove Weld Defects and Corrective Actions

Common groove weld defects may be noticed during the welding operation or later during the inspection of the completed weld. These defects are listed and illustrated with suggestions for corrective actions.

Lack of (incomplete) penetration. A weld that does not properly penetrate into the weld joint.

How to correct:
- Open groove angle.
- Decrease root face.
- Increase root opening.
- Increase amperage.
- Decrease arc length.
- Decrease travel speed.
- Decrease torch angle.

Lack of fusion. Fusion did not occur between the weld metal and fusion faces or adjoining weld beads.

How to correct:
- Clean weld joint before welding.
- Remove oxides from previous welds.
- Open groove angle.
- Decrease root face.
- Increase root opening.
- Increase amperage.
- Decrease arc length.
- Decrease travel speed.
- Decrease torch angle.
Overlap. Weld metal that has flowed over the edge of the joint and improperly fused with the base metal.  
How to correct:  
• Clean edge of weld joint.  
• Remove oxides from previous welds.  
• Reduce size of bead.  
• Increase travel speed.  

Undercut. Lack of filler metal at the toe of the weld metal.  
How to correct:  
• Decrease travel speed.  
• Increase dwell time at edge of joint on weave beads.  
• Decrease arc length.  
• Decrease amperage.  
• Decrease torch angle.  

Concave weld. A concave weld occurs when insufficient metal is added to fill the joint above the groove edges.  
How to correct:  
• Add additional filler metal on the fill passes.  
• Use stringer beads on crown pass.  

Convex crown. A weld that is peaked in the center.  
How to correct:  
• Use less filler metal on the crown bead.  

Craters. Formed at the end of a weld bead due to a lack of weld metal fill or weld shrinkage.  
How to correct:  
• Do not stop welding at end of joint (use tabs).  
• Fill craters to the proper crown height and reduce amperage slowly.  

Cracks. Caused by cooling stresses in the weld and/or base metal.  
How to correct:  
• Use wire with lower tensile strength or different chemistry.  
• Increase joint preheat to slow the weld cooling rate.  
• Allow joint to expand and contract during heating and cooling. Increase size of the weld.  

Porosity. Caused by entrapped gas that did not have enough time to rise through the melt to the surface.  
How to correct:  
• Remove all heavy rust, paint, oil, or scale on joint before welding.  
• Remove oxide film from previous passes or layers of weld.  
• Protect welding area from wind.  
• Remove all grease and oil from the filler metal. Handle filler metal with clean gloves.  
• Check gas supply for flow rate, possible contamination, loose connections, dirty torch nozzle.  

Linear porosity. Forms in a line along the root of the weld at the center of the joint where penetration is very shallow.  
How to correct:  
• Make sure root faces are clean.  
• Increase current.  
• Decrease arc length.  
• Increase amperage.  
• Decrease travel speed.
Melt-through. Occurs at a gap in the weld joint or place where metal is thin.

How to correct:
• Decrease current.
• Increase arc length.
• Increase travel speed.
• Decrease root opening.

Concave root surface. The root of the weld penetration does not extend below the lower edges of the joint.

How to correct:
• Decrease travel speed.
• Decrease amperage.
• Decrease arc length.
• Increase filler wire deposition.

Icicles. Weld penetration beyond the joint root is uneven.

How to correct:
• Move the torch throughout the weld length in a consistent pattern.
• Add filler metal as required to maintain an even penetration.

Fillet Weld Defects and Corrective Actions

Common fillet weld defects may be noticed during the welding operation or later during the inspection of the completed weld. These defects are listed and illustrated with suggestions for corrective actions.

Lack of penetration. Insufficient weld metal penetration into the joint intersection.

How to correct:
• Maintain slight forward torch angle.
• Increase amperage.
• Decrease arc length.
• Decrease size of weld deposit.
• Use stringer beads.
• Do not make weave beads on root passes.

Lack of fusion. Occurs in multiple-pass welds where layers do not fuse.

How to correct:
• Remove oxides and scale from previous weld passes.
• Increase amperage.
• Decrease arc length.
• Decrease travel speed.

Overlap. Occurs in horizontal, multiple-pass fillet welds when too much weld is placed on the bottom layer.

How to correct:
• Remove oxides and scale from weld area.
• Reduce the size of the weld pass.
• Increase travel speed.

Undercut. Occurs at the top of the weld bead in horizontal fillet welds.

How to correct:
• Make a smaller weld.
• Make a multiple-pass weld.
• Decrease amperage.
• Decrease arc length.
Concave weld. A concave weld is formed when insufficient metal is added to the molten pool.

How to correct:
- Deposit more material into the pool with each application of the filler metal.

Convex weld. A weld that has a high crown.

How to correct:
- Deposit less metal into the pool with each application of the filler metal.

Craters. Formed when weld metal shrinks below the full cross-section of the weld.

How to correct:
- Do not stop welding at the end of the joint (use tabs).
- Using the same travel torch angle, move the torch back on the full cross section before stopping.

Cracks. Occur in fillet welds just as they do in groove welds.

How to correct:
- Use suggestions for groove weld cracks.

Excessive penetration. Formed when excessive heat is applied to the upper part of the joint.

How to correct:
- Change torch angle to lower plate.
- Decrease bead size.
- Increase welding speed.
- Use chill bar behind joint to remove excessive heat.

Melt-through. Occurs when the molten pool melts through the base material and creates a hole.

How to correct:
- Change torch angle to lower plate.
- Decrease bead size.
- Increase welding speed.
- Use chill bar behind joint to remove excessive heat.

Concave root surface. The molten weld penetration has retracted from the root surface.

How to correct:
- Increase welding speed.
- Decrease amperage.
- Increase arc length.
- Increase filler metal feed.

Postweld Treatment

Postweld treatment depends on the type of material welded, joint restraint, and the desired mechanical values. In postweld treatment, the cooling rate of the welded part is controlled, allowing the mechanical properties of the metal to return to a normal condition. Cooling some materials too rapidly severely affects their mechanical properties, such as making the part very hard and brittle. Preweld and postweld heat treatments are used on steels with higher carbon content, castings, and other materials that are prone to cracking.

A stress-relieving operation performed on carbon steels at approximately 1150°F (621°C) removes residual stresses caused by weld shrinkage. This can be done by local or furnace heating. The weld area is heated to 1150°F (621°C) and this temperature is maintained for one hour per inch of material thickness. The part can then be air-cooled. Low-alloy steels can be stress-relieved in the same manner; however, the cooling period should be lengthened by covering the part with heat-resistant materials.
Types of steel include carbon steels, low-alloy steels, heat-treated steels, and tool steels. Carbon steels are classified as low-, medium-, and high-carbon steels. Alloying elements in low-alloy steels include chromium, molybdenum, nickel, vanadium, and manganese. Heat treatments include quenching, tempering, and annealing. Tool steels are steels with a combination of high carbon and alloy content.

Common steel forms include hot-rolled steel, cold-rolled steel, castings, and forgings. Steels are manufactured to specifications developed by various organizations, including ASTM International.

Filler metals must be selected to produce the desired mechanical properties in the weldment after any required welding or heat treatment. When selecting a steel filler metal, the type of steel to be welded and the possibility of excessive porosity within the completed weld should be considered.

Joint preparation considerations include removing oxide film from edges prepared by thermal cutting processes, providing weld backing where needed, and preheating. Quenched and tempered steel requires preheat and interpass temperature control to retain the original mechanical properties of the metal.

Two torch angles that affect how the weld bead is placed into the weld joint are the work angle and travel angle. Work angles usually split the weld pool evenly between the two pieces of base metal. A good travel angle allows the welder to see the weld pool.

Stringer beads, or stringer passes, are welds made without oscillation of the torch. Weave beads are welds made with torch oscillation.

Thoriated, lanthanated, ceriated, zirconiated, and pure tungsten electrodes can be used for welding steel. Lanthanated electrodes work well for either ac or dc current and have good current-carrying capacities. Higher welding amperages require larger electrodes. An electrode that is sharpened to a point with a slight flattened tip is recommended for welding steel.

Pure argon gas can be used when welding metal up to 1/8" (3.2 mm) thick. For increasing thicknesses, helium should be added to the shielding gas.

Manual GTAW requires a great deal of skill to perform correctly. The ability to read a weld pool must be developed so that the welder can make the appropriate adjustments to ensure a quality weld.

Review Questions

1. What are the three classifications of carbon steel?
2. Medium-carbon steel has a content of _____ carbon.
3. List three alloying elements commonly used to make low-alloy steels.
4. What is heat treating?
5. The oxide film on the surface of hot-rolled steel is _____ in color.
6. What color is the surface of castings that have been sandblasted?
7. Why should stainless steel filler metals not be used for welds in service over 1000°F (538°C)?
8. List the three finishes available on steel filler metals.
9. Why must the oxide scale be removed from the edges of thermally cut joints before use?
10. What two types of backing are used when welding 100% penetration steel welds?
11. Why is backing used for 100% penetration steel welds?
12. When are carbon steels less than 1" (25.4 mm) thick and with less than .30% carbon preheated?
13. What causes low-alloy steels to have hard heat-affected zones after welding?
14. What is the main reason for maintaining a good travel angle?
15. The welding rod to be added to the molten pool is held at what angle?
16. Tool steels should be welded with small _____ beads to reduce the amount of heat input and expansion of the base material.
17. At what approximate temperature can postweld stress relief of carbon steel weldments be done?
18. Welds made without any side-to-side movement of the torch are called _____ beads.
19. Welds made with side-to-side movement of the torch are called _____ beads.
20. When steel is being welded, a small white dot may form on the top of the molten metal. What is this material?