



Nonferrous Metals for Welding 205

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Class Outline

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Properties of Metals
Types of Properties
Types of Strength
Other Mechanical Properties
Physical Properties
The Effects of Heat
Heat Treatment
Weldability
Common Nonferrous Welding Metals
Properties of Aluminum
Aluminum Alloys
Welding Aluminum Alloys
Properties of Copper
Welding Copper Alloys
Welding Magnesium Alloys
Welding Nickel Alloys
Welding Zinc Alloys
Welding Titanium Alloys
Summary

Lesson: 1/20

Objectives

- Explain the importance of a metal's properties.
- Distinguish between mechanical and physical properties.
- List the different types of strength.
- List common types of mechanical properties.
- List common types of physical properties.
- Describe how heat affects the properties of metal.
- Describe the effects of common heat treatment methods for nonferrous metals.
- Identify the factors that affect weldability.
- Identify common types of nonferrous metals used in arc welding.
- Describe the properties of aluminum.
- Identify common groups of aluminum alloys.
- Describe the weldability of aluminum alloys.
- Describe the properties of copper.
- Describe the weldability of copper alloys.
- Describe the weldability of magnesium alloys.
- Describe the weldability of nickel alloys.
- Describe the weldability of zinc alloys.
- Describe the weldability of titanium alloys.



Figure 1. Aluminum has good weldability because of its high strength properties.



Figure 2. Copper-coated electrode wire is frequently used because of its high electrical conductivity.

Lesson: 2/20

Properties of Metals

Some people might assume that welders only need to learn how to make a **weld**, like the one shown in Figure 1, and not understand the engineering behind welding. However, welders who understand the **properties** of the metals they are welding can increase the quality of the weld. Properties are the characteristics of metals that make them useful and different from other metals.

Arc welding demands that a metal's properties must match the requirements of a specific welding process. The metal in the welded **joint** must have properties equal to or better than the properties of the **base metal**. Understanding these principles reduces errors that could weaken the weld.

Every welder at one time or another works with steel. However, a welder must also learn how to weld the various **nonferrous metals** that have their own unique properties. This class will teach you about the common types of nonferrous metals and their alloys. You will also learn the different properties of nonferrous metals and how they affect the weld.



Figure 1. An aluminum weld.

Lesson: 3/20

Types of Properties

The properties of a metal are split into two categories: mechanical properties and physical properties.

Mechanical properties determine how well the metal stands up to some kind of force applied against it. In other words, mechanical properties describe the way a metal bends, stretches, dents, scratches, or breaks. When force is applied to a metal, you can determine its properties by the way it behaves. Common mechanical properties that affect metals include **strength, ductility, toughness,** and **hardness.** Figure 1 shows a machine designed to test a metal's strength.

Physical properties of metals describe the physical characteristics of metals that do not relate to force. Metals can melt, expand, emit heat, and conduct electricity. Common physical properties include **corrosion resistance, electrical conductivity, thermal conductivity, thermal expansion,** and **melting temperature.** For example, the cooking pan in Figure 2 has a copper bottom because it effectively conducts heat.

Every metal has mechanical and physical properties. The way a metal behaves under specific conditions tells you about its properties and how it differs from other metals. Understanding which properties exist in a metal allows welders to choose the metals that meet the requirements of a specific welding process.



Figure 1. This machine tests a sample metal's strength by pulling it apart.



Figure 2. The thermal conductivity of copper makes it very suitable for cooking pans.

Lesson: 4/20

Types of Strength

The strength of a metal is the most important mechanical property to a welder. **Strength** is the ability of the metal to withstand some kind of force without breaking or changing its shape.

Strength is divided into more specific properties. **Tensile strength** is the resistance of a material to a force that is trying to pull it apart. It is generally the most important property when evaluating metals. **Yield strength** is the maximum stress the metal will support without permanent deformation. A metal with high yield strength is needed to manufacture parts that must remain intact without breaking, like the boat in Figure 1.

Compressive strength is the material's resistance to a force that is trying to crush it. If you apply pressure to two metals, and one cracks before the other, this indicates the metal's compressive strength. However, cracking also occurs in metals subjected to various types of force.

These are just a few types of strength properties. Keep in mind that a metal will eventually fail under any of these strengths if the amount of force is increased sufficiently. Nevertheless, every welded joint must meet specific welding requirements. When welders know the strength of the weld metal compared with the base metal, they avoid overwelding or underwelding the joint.



Figure 1. This aluminum boat must have high yield strength.

Lesson: 5/20

Other Mechanical Properties

Besides strength, a metal has other mechanical properties that determine its usefulness:

- **Ductility** is the ability of a metal to stretch and become permanently deformed without breaking or cracking. For many applications, ductility is one of the key properties required in a welded joint.
- **Hardness** is the ability of a metal to resist indentation, penetration, abrasion, and scratching. The heat from welding may change the hardness of the welded metals. Many times, there is a difference in hardness between the base metal and the weld metal. This often indicates a difference in strength and other properties as well.
- **Toughness** is the ability of a metal to withstand the sudden shock of a rapidly applied force. Many times, toughness is a combination of other properties, such as strength and ductility. The combination of high tensile strength and toughness is important in many welded structures. However, defects in the weld metal and a lack of toughness led to the failure of the weld in Figure 1.



Figure 1. Small cracks and a lack of toughness led to failure of the weld.

Lesson: 6/20

Physical Properties

The way metals melt, emit heat, conduct electricity, and expand or shrink depends on their **physical properties**:

- **Corrosion resistance** is the ability of a metal to resist attack by other elements and chemicals. The most common form of corrosion occurs when metals react with oxygen and form rust. Certain nonferrous metals are chosen specifically because of their corrosion resistance, like the aluminum car frame in Figure 1.
- **Melting temperature** is the temperature at which a metal melts into a liquid. Figure 2 compares the melting temperatures of two common metals. Arc welding a metal with a low melting temperature requires less heat and more control of the process to prevent melting through the metal.
- **Electrical conductivity** describes how easily electrical current flows through a metal. Certain metals are more conductive than others. Metals that resist electrical current require a higher voltage to force current through the metal.
- **Thermal conductivity** is the rate at which heat flows through a metal. Arc welding involves significant heat, which affects the properties of the weld metal and base metal.
- **Thermal expansion** is the increase in the dimensions of a metal due to an increase in its temperature. Since weld metal is constantly heated and cooled, these changes have an effect on the metal's properties.



Figure 1. This aluminum car frame offers corrosion resistance.

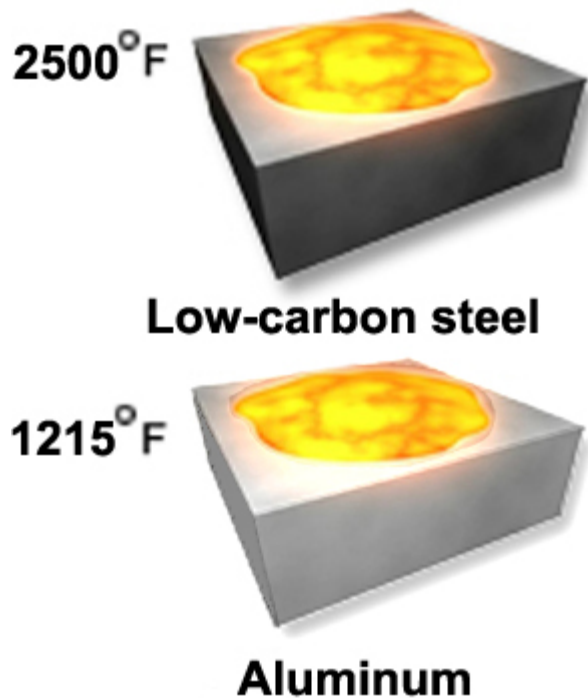


Figure 2. The melting temperature of aluminum is much lower than steel.

Lesson: 7/20

The Effects of Heat

During arc welding, a metal's properties do not stay the same. Arc welding adds heat to metals. This intense heat often changes the properties that exist in a welded metal.

Arc welding involves high temperatures and a sequence of temperature changes. First, the metal is heated, then the **electrode** deposits the weld metal, and finally, both the weld deposit and the base metal cool. The rate at which the weld cools changes the **grain structure** in the weld metal and the base metal immediately next to it. This area is known as the **heat-affected zone (HAZ)**. The properties of the metal in the HAZ depend on the type of metal and the rate at which it is heated and cooled.

The way in which a metal responds to heat depends on its properties. The heat from welding softens all metals, which reduces their hardness. Because nonferrous metals have different properties than ferrous metals, they react to heat in different ways. Many times, nonferrous base metals are cold worked. **Cold working** is the shaping of metal at temperatures below the point of **recrystallization**. Cold working increases the hardness and strength of a metal. Metals that have been cold worked often require special **heat treatment** processes in order to obtain the desired results after welding.

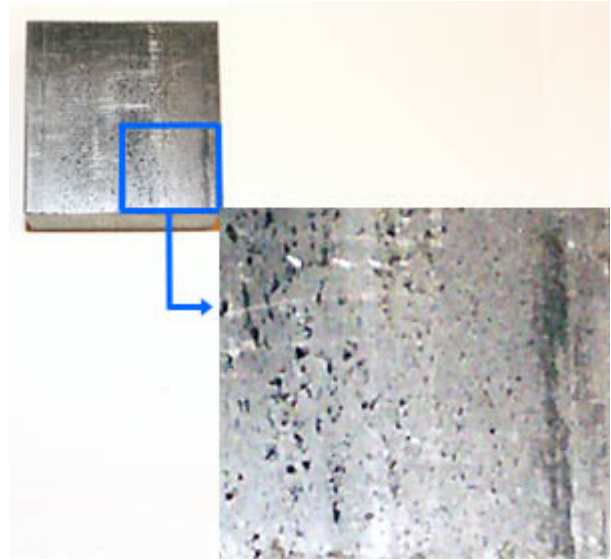


Figure 1. A closeup view of a metal surface that has been cold worked.

Lesson: 8/20

Heat Treatment

The heat from arc welding produces molten weld metal, which then cools to form a solid weld. For almost every weld that cools and solidifies too quickly, it becomes extremely hard, which may result in **cracking** and other defects.

Welds that have a fast cooling rate may require **heat treatment**. Heat treatment is the controlled heating and cooling of a metal in order to alter its mechanical properties. The graph in Figure 1 shows the level of temperature increase often required to change a metal's properties. To avoid an extremely hard weld, welders often preheat the base metal. **Preheating** the base metal to a specific temperature and maintaining it during welding slows the cooling rate and practically eliminates hardness. Welders often use a **gas torch** or special types of heaters for preheating.

Some nonferrous metals require preheating of the base metals to increase their strength properties. However, many nonferrous metals have been cold worked and are extremely hard. These metals require a heat treatment method known as **annealing** to soften the metals during welding. Another common nonferrous heat treatment method is known as **solution heat treating**. This method causes one element to dissolve in another when it normally would not, increasing strength and hardness properties. For example, the tensile strength of many nonferrous alloys increases when the materials within the alloy go into a solid solution and then are allowed to **precipitate** out. Controlling the rate and extent of the return of these materials is called **precipitation hardening**.

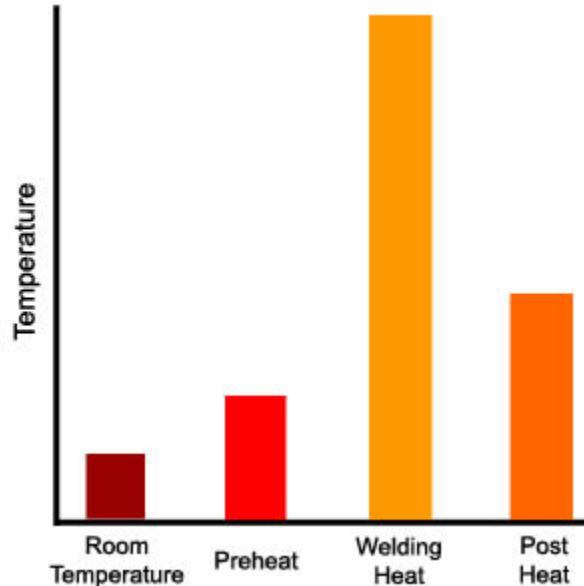


Figure 1. Heat treatment controls the cooling of a metal in order to alter its properties.

Lesson: 9/20

Weldability

Each type of metal consists of different properties that distinguish it from other metals. These particular properties determine the metal's **weldability**. Weldability is the ability of a metal to be welded under certain imposed conditions into a specific structure, which performs efficiently for its intended use. In other words, weldability is the measure of how easy it is to weld a particular material with a specific welding process without problems or defects.

Weldability is the result of three factors: composition, mechanical properties, and heat treatment. Mechanical properties such as hardness and toughness help determine weldability.

Although most welded metals are **ferrous metals**, many types of nonferrous metals have desirable properties suitable for arc welding. For example, **aluminum** is one of the most weldable of all metals because of its high strength properties. Figure 1 shows aluminum welding. The combination of a metal's unique properties determines its weldability.

The exact weldability can be difficult to determine. Essentially, some metals are easier to weld than others. Weldability is not a fixed value. However, factors such as joint type, welding process, and part specifications help determine weldability.



Figure 1. Aluminum has good weldability because of its high strength properties.

Lesson: 10/20

Common Nonferrous Welding Metals

Ferrous metals contain iron, and they are the most commonly welded metals. However, knowledge of **nonferrous metals** is essential because they provide different options when steels are not suitable for a particular job.

Nonferrous metals do not contain iron. This group includes metals that offer a wide range of properties:

- **Aluminum** (Figure 1) is a silvery, lightweight, but strong metal known for its corrosion resistance and high thermal conductivity. Aluminum is easy to weld if the proper techniques are applied.
- **Copper** (Figure 2) is a reddish-brown, ductile metal known for its high electrical and thermal conductivity. Copper is the primary metal in brass and bronze.
- **Magnesium** is a silver-white, strong, ductile metal, which is often used in alloys. Magnesium is often alloyed with aluminum to give it the desired properties.
- **Zinc** is a bluish-white, hard metal often used as an alloy with copper in brass. Zinc has excellent corrosion resistance and other alloying properties.
- **Nickel** (Figure 3) is a silvery, tough metal with excellent corrosion resistance. Nickel alloys easily with many metals and is the main alloy in many types of **steels**.
- **Titanium** is a silver-gray, strong, but lightweight metal with excellent corrosion resistance. Titanium is stronger than steel, and its alloys are often used in the aerospace industry.

Some of these metals are weldable in their pure form. However, most of them are used as an **alloy** with other metals to create desirable properties, which increases their weldability.



Figure 1. Aluminum is known for its high thermal conductivity.

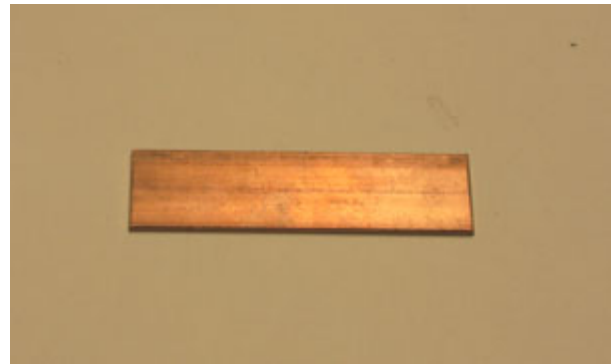


Figure 2. Copper is known for its high electrical conductivity.

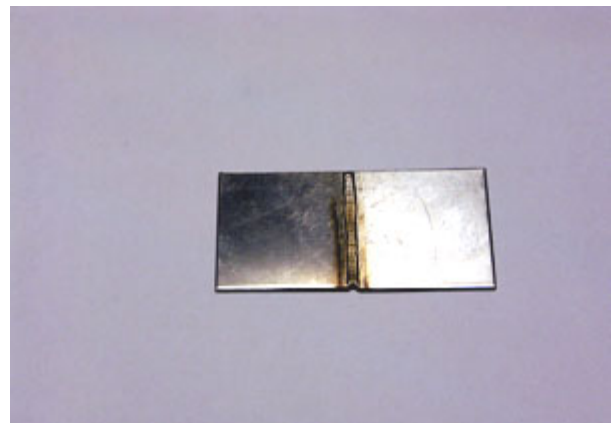


Figure 3. Nickel is known for its excellent corrosion resistance.

Lesson: 11/20

Properties of Aluminum

Aluminum is one of the most weldable metals. While **steel** may be a more commonly welded metal, both metals have good weldability. Nevertheless, aluminum has unique properties that make it very different from steel. These properties determine the appropriate welding process and heat treatment required. Figure 1 shows the microstructure of pure aluminum.

Aluminum is three times lighter than steel but still offers higher strength when alloyed with certain elements. Figure 2 shows a magnified image of aluminum with an added element. Also, aluminum has high thermal conductivity, which means that heat flows through aluminum faster. Finally, aluminum has a low melting temperature. However, because of aluminum's high thermal conductivity, more welding heat is required for aluminum, even though its melting temperature is half that of steel. Higher heat input can lead to **burnthrough** or warpage if special procedures are not followed.

Because of these properties, special welding equipment and procedures are necessary, especially for thicker sections of aluminum. Nevertheless, it is important not to overheat the metal or hold the temperature on the metal longer than necessary.

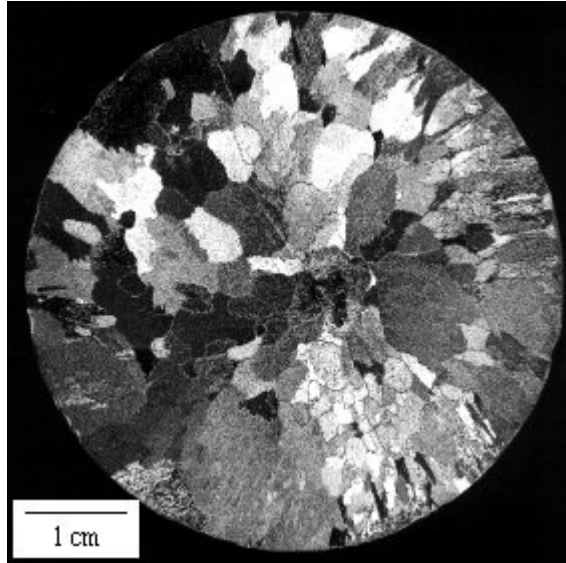


Figure 1. Magnified image of pure aluminum. (Courtesy of Internet Microscope, Manchester Materials Science Centre, UMIST, and University of Manchester, UK.)

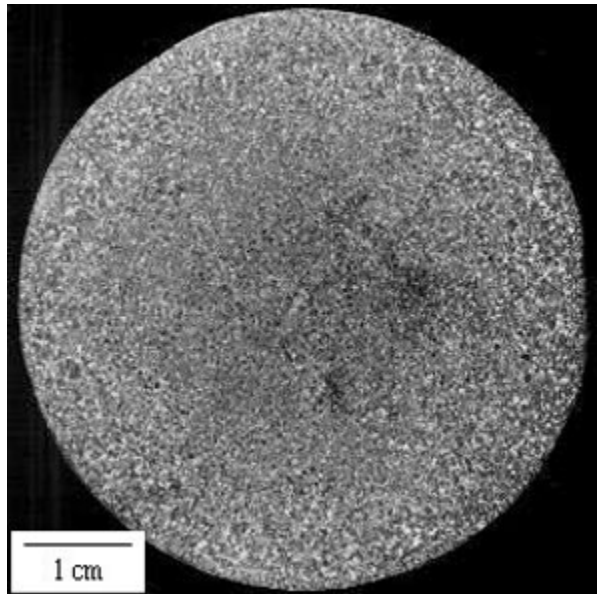


Figure 2. The addition of titanium changes the grain structure and adds strength. (Courtesy of Internet Microscope, Manchester Materials Science Centre, UMIST, and University of Manchester, UK.)

Lesson: 12/20

Aluminum Alloys

Aluminum can be alloyed with a number of elements. The most common alloys include copper, silicon, manganese, magnesium, and zinc. These alloys provide higher strength, corrosion resistance, and general weldability.

Aluminum alloys are classified into nonheat-treatable alloys and heat-treatable alloys. **Nonheat-treatable alloys** rely primarily on cold working to increase their strength properties. The strength of these alloys usually depends on the hardening effect of other alloy elements.

Heat-treatable alloys can be heated after welding to regain strength lost during the welding process. To heat treat an alloy, the solution heat treatment method is used. This method places the alloy in a solid solution and cools it at a rate which produces a **supersaturated solution**. The next step is to maintain the solution at room temperature long enough to allow a controlled amount of the alloying elements to **precipitate**, which increases the alloy's hardness. The aluminum-copper alloys in Figure 1 shows a concentrated amount of copper in a supersaturated solution.

Aluminum and its alloys are primarily used on applications that require good strength, light weight, and high thermal and electrical conductivity. For example, the aluminum base plate in Figure 2 is used to minimize weight for workholding components. Keep in mind that most aluminum alloys, like steel, have good weldability. However, their unique characteristics demand highly skilled welders.

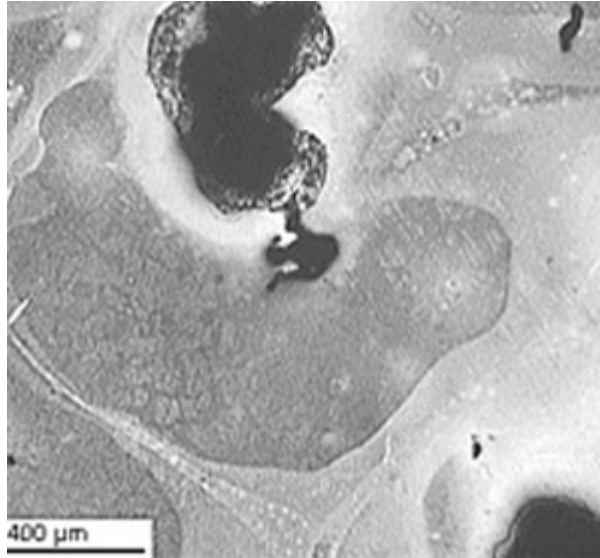


Figure 1. The dark spot in this aluminum-copper microstructure represents a concentration of copper that precipitated out of the supersaturated solution. (Courtesy of Internet Microscope, Manchester Materials Science Centre, UMIST, and University of Manchester, UK.)



Figure 2. Lightweight aluminum plates are used to make workholding components.

Lesson: 13/20

Welding Aluminum Alloys

Aluminum and its alloys are some of the most weldable metals. However, aluminum has unique properties that must be considered before welding.

The surface of aluminum contains **aluminum oxides** that must be cleaned before welding. Aluminum oxides form when oxygen contacts aluminum's surface and creates a thin film. If this film is not removed, the aluminum may melt beneath it, which results in poor fusion and entrapped oxides from the film coating. Figure 1 shows a clean aluminum weld.

Another unique characteristic of aluminum is that there is no color change when it is heated. In turn, welders must assume a welding position where they can witness the melting of the base and **filler metals** under the arc. Consequently, this necessitates a longer arc length so the welder can see the arc and the weld pool.

Aluminum welding must be performed "hot and fast." The high thermal conductivity of aluminum demands higher amperages and voltage settings, as well as higher travel speed. If the travel speed is too slow, excessive burnthrough and distortion may occur.

Most often, welders use GTAW or GMAW for welding aluminum. GTAW is best suited for welding thin **gauge** aluminum, as you can see in Figure 2, because of aluminum's light weight and unique properties. On the other hand, Figure 3 shows a GMAW weld. GMAW is often the first choice used to weld aluminum because it is a fast and versatile process.



Figure 1. The film coating from this aluminum weld sample has been removed.



Figure 2. The thin gauge aluminum has been welded using GTAW.



Figure 3. A sample of a GMAW weld.

Lesson: 14/20

Properties of Copper

Copper, along with its alloys, is another common nonferrous metal. Like aluminum alloys, copper alloys have unique properties that distinguish them from the different types of steel.

There are hundreds of different copper alloys. The principal alloying elements are aluminum, nickel, silicon, tin, and zinc. Each alloy consists of different properties that determine its weldability. **Brass** is the most common type of copper alloy, which contains zinc as the primary alloying element. However, **bronze** is the most weldable copper alloy.

Copper has the highest electrical conductivity of all the commercial metals. As you can see in Figure 1, copper is widely used for electrical conductors and wiring and in electrical equipment, like the copper-coated electrode wire in Figure 2. Also, like aluminum, copper has high thermal conductivity. In fact, it has the highest thermal conductivity of all the metals. This makes it harder to melt, even though its melting temperature is much lower than steel's. Copper also has high **thermal expansion**, which causes the metal to expand more when heated and contract more when cooled.

All of the copper alloys get their strength from cold working. However, the heat from welding softens the metal and can reduce its strength. However, this is only temporary depending on its cooling rate. Consequently, **post heating** the weld may be required to restore strength properties.



Figure 1. Copper wire is often used for electrical conductors.



Figure 2. Copper-coated electrode wire used for GMAW.

Lesson: 15/20

Welding Copper Alloys

Some copper alloys are more weldable than others. Most copper alloys must be preheated due to their high thermal conductivity. Preheating is the most common method used to offset the effects of thermal conductivity. Preheating reduces welding heat input and keeps the softening of the HAZ to a minimum. Also, using higher current to weld copper often minimizes the loss of heat. In addition, the high thermal expansion of copper often results in weld distortion. The high contraction of the metal as it cools increases weld cracking. Preheating the base metal and applying **tack welds** minimizes cracking.

Of all the copper alloys, the **copper-tin alloys**, or bronzes, are the most weldable. Figure 1 shows the magnified microstructure of bronze. **Tin** adds strength and hardness to copper and gives off fewer fumes compared to other alloys. **Copper-zinc alloys**, such as brass, are weldable, but they have certain drawbacks. Copper-zinc alloys give off offensive fumes, which result in the need for proper ventilation equipment. Consequently, low-zinc alloys are more weldable than high-zinc alloys. Figure 2 shows the magnified microstructure of brass.

Copper-lead alloys have the poorest welding properties. Often, during welding the **lead** becomes oxidized before the copper melts, resulting in contamination and porous welds. Because small amounts of toxic elements are often present in copper, effective ventilation equipment to protect the welder is critical.

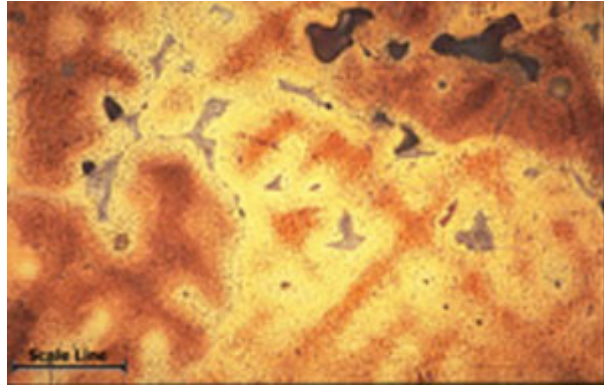


Figure 1. Microstructure of bronze. (Courtesy of The Copper Development Association).

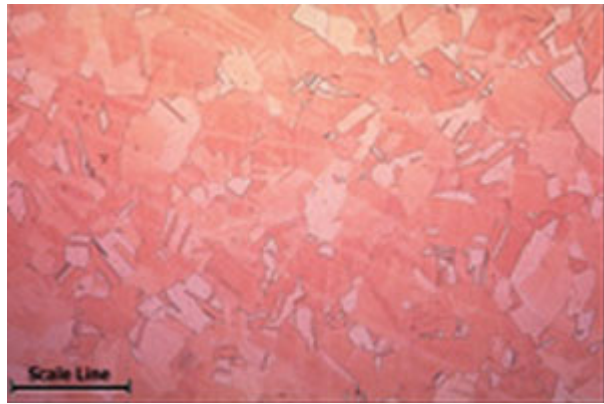


Figure 2. Microstructure of brass. (Courtesy of The Copper Development Association).

Lesson: 16/20

Welding Magnesium Alloys

Magnesium is a silvery-white, ductile metal that is much lighter than steel and even lighter than aluminum. For example, the engine block in Figure 1 is large, but it is also extremely light. Pure magnesium is not very weldable because of its low strength. However, magnesium alloys are stronger and can be hardened by **precipitation hardening**.

Magnesium alloys usually contain aluminum, manganese, and zinc. Aluminum added to magnesium gives the best results because it increases strength and hardness. Magnesium alloys are heat treated to improve their mechanical properties. Like aluminum alloys, magnesium alloys have low melting points and high thermal expansion. However, although magnesium requires less heat input for melting, high thermal expansion tends to cause distortion.

The weldability of magnesium alloys is generally good when the proper **filler metal** is used. These alloys cannot be welded to other metals because of the brittle, metallic compounds that tend to form. The combination of magnesium with other metals often contributes to corrosion. Magnesium alloys are usually welded with GTAW. The GTAW arc melts the metal so quickly that the metal is solid again before the heat has penetrated very far into the workpiece. This reduces the contracting stresses during cooling that cause cracking.



Figure 1. This engine block is made of magnesium.

Lesson: 17/20

Welding Nickel Alloys

Nickel is a silvery, tough metal with excellent corrosion resistance. Nickel alloys easily with many metals and is the main alloy in many types of steels. Nickel can also be used as a coating, as is the case with the hoist ring in Figure 1.

Nickel alloys are easily joined by most welding processes. Welding processes similar to those used on steel are often used for nickel and nickel alloys. **Wrought nickel alloys** are often welded under conditions similar to those used to weld **austenitic stainless steels**. However, **cast nickel alloys** may present welding difficulties. This is because cast nickel alloys contain significant amounts of **silicon**. As silicon content increases, the possibility of weld cracking also increases.

The mechanical properties of nickel alloys vary depending on the amount of cold work remaining in the base metal or the amount of hardness remaining in the metal. If the base metal is too hard, it requires **annealing** before welding. Corrosion resistance usually remains in the weld metal because it is similar to the base metal. However, the welding heat affects the corrosion resistance in the HAZ. Consequently, welds made on certain nickel alloys are commonly solution heat treated after welding to restore corrosion resistance in the HAZ.

Because nickel alloy weld metal does not spread or flow easily, it is important that welders place the weld metal accurately in the joint, as Figure 2 shows. This often requires welders to **weave** the electrode.



Figure 1. This hoist ring is coated with nickel to prevent corrosion.

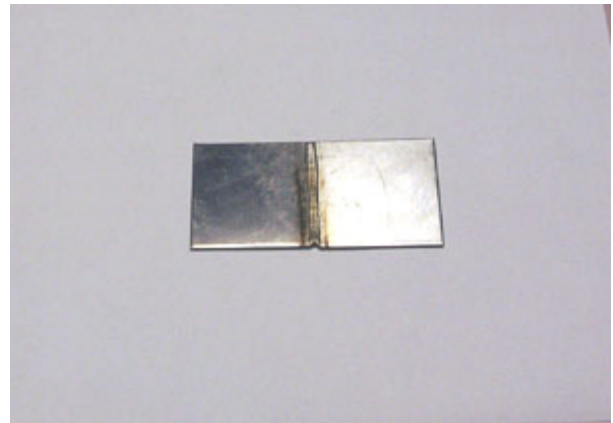


Figure 2. A nickel weld.

Lesson: 18/20

Welding Zinc Alloys

Zinc is most commonly used as a protective coating on steel because of its high corrosion resistance. The process of adding a zinc coating to steel is known as **galvanizing**. Galvanized steel is often used to manufacture car parts, building frames, and ducting.

When welding zinc-coated steels, keep in mind that the **boiling point** of zinc is below the **melting temperature** of steels. This may cause significant fuming to occur during welding. For this reason, welds should be performed on areas that are free of zinc. In this case, the zinc can be removed by **grinding** the intended weld zones. However, while a zinc-free weld is preferred, it is not a requirement. The weld in Figure 1 is on galvanized steel.

GMAW and FCAW are often used to weld zinc-coated steels. If the coating has not been removed, higher heat input is often required to remove the zinc from the weld pool. Also, lower travel speed is often used to burn off the zinc coating ahead of the molten weld pool.

Zinc is also alloyed with aluminum, copper, or lead to add specific properties to the metal. The spring stop in Figure 2 contains zinc and aluminum. Copper-zinc alloys are the most common alloys and are used to make brass. Figure 3 shows the magnified microstructure of brass containing 30% zinc. However, only low-zinc brasses can be welded due to the dangerous fumes that they produce. Most zinc alloys require joining processes other than arc welding.



Figure 1. A galvanized steel weld.



Figure 2. This spring stop component contains zinc and aluminum.

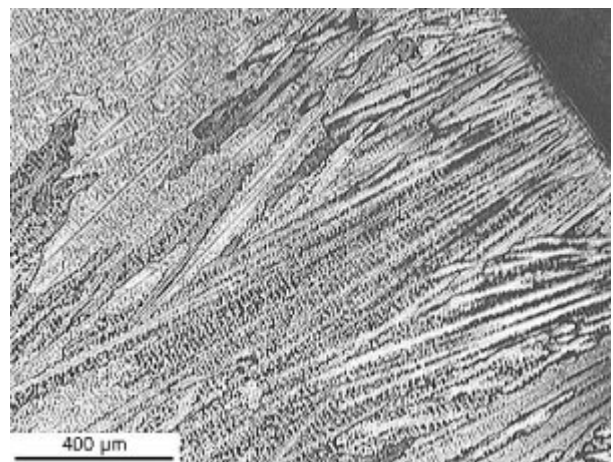


Figure 3. Microstructure of brass containing 30% zinc.

Lesson: 19/20

Welding Titanium Alloys

Titanium is a silver-gray metal that is stronger than steel yet as light as aluminum. Titanium alloys can be welded by procedures used to weld austenitic stainless steels and aluminum. However, titanium is a highly reactive metal and often requires special welding procedures.

The key to titanium welding is adequate shielding. When titanium is heated to temperatures above 1000°F, it becomes highly reactive with the elements in the air, especially oxygen and nitrogen. This reaction causes surface contamination. Welders must take precautions to protect the weld from these elements. Inert shielding gases, such as **argon**, must be used to protect the weld puddle and the HAZ. Also, titanium base metal must be thoroughly cleaned before welding to remove any dirt, rust, or other contaminants from the weld. A stainless steel wire brush is often used to clean titanium before welding.

The quality of a titanium weld is often judged by its coloring. A titanium weld should have a bright, silver appearance. Yellowish to bluish colors, like those on the weld in Figure 1, sometimes indicate hardening, while dark blue colors or a gray oxide layer often point to inadequate shielding and brittleness.

GTAW and GMAW are often used to weld titanium. GTAW is the most widely used process, especially for thin sections, while GMAW is used for thick sections. Fluxes cannot be used because they combine with titanium to cause brittleness and may reduce corrosion resistance.



Figure 1. A titanium weld.

Lesson: 20/20

Summary

Welders must understand the properties of the metals they are welding. Mechanical properties determine how well the metal stands up to some kind of force applied against it. This includes strength, ductility, toughness, and hardness. Physical properties describe the physical characteristics of metals that do not relate to force. These include corrosion resistance, electrical conductivity, thermal conductivity, thermal expansion, and melting temperature.

The intense heat generated during arc welding changes the properties of the weld metal and base metal. This area is called the heat affected zone, or HAZ. The effect that heat has on a base metal determines the weldability of the metal and its usefulness. Weldability is the ability of a metal to be welded under certain imposed conditions into a specific structure, which performs efficiently for its intended use. Some metals require heat treatment, which is the controlled heating and cooling of a metal to alter its properties.

Although they are not as popular as ferrous metals, nonferrous metals provide different options when steels are not suitable. Aluminum is the most commonly welded nonferrous metal. Aluminum is a lightweight, strong metal known for its high thermal conductivity. Because of this property, aluminum welding must be performed at higher amperages and higher travel speed. GMAW is the first choice for welding aluminum.

Other nonferrous metals include copper, magnesium, zinc, nickel, and titanium. Copper is also a very common nonferrous metal. It is known for its high electrical and thermal conductivity. Of all the copper alloys, the bronze alloys are the most weldable. The brass alloys can also be welded. However, increasing amounts of zinc causes fuming, which makes them less weldable.

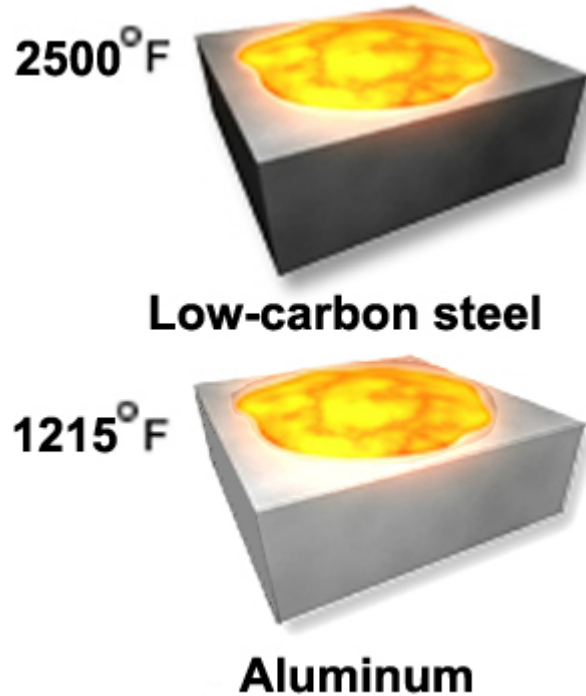


Figure 1. Aluminum has a much lower melting point than steel.

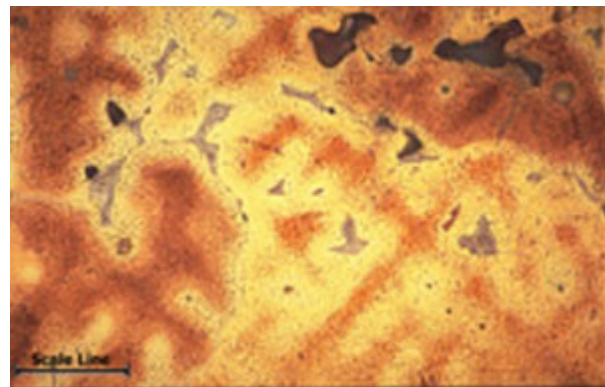


Figure 2. The magnified bronze microstructure contains amounts of copper and tin.

Class Vocabulary

- alloy** A metal consisting of a mixture of two or more materials. One of these materials must be a metal.
- aluminum** A silver-white metal that is soft, light, and conductive.
- aluminum oxide** A chemical compound of aluminum and oxygen, which forms a thin layer on the surface of aluminum when exposed to air. Aluminum oxides should be removed before welding.
- annealing** The steady heating of a metal at a certain temperature followed by a gradual cooling process. Annealing is often used when welding nonferrous metals.
- arc welding** A fusion welding process that uses electricity to generate the heat needed to melt the base metals.
- argon** A colorless, odorless type of inert gas. Argon is commonly used as shielding gas.
- austenitic stainless steel** Stainless steel with very high strength, as well as excellent ductility and toughness. Austenitic stainless steel is the most corrosion-resistant stainless steel.
- base metal** One of the two or more metals to be welded together to form a joint.
- boiling point** The temperature at which a liquid changes to a vapor. The boiling point of zinc is below the melting temperature of most steels.
- brass** An alloy of copper and zinc. Brass has poor weldability.
- bronze** An alloy of copper and tin. Bronze is the most weldable of the copper alloys.
- burnthrough** Excessive melt through or a hole in the base metal. Extremely high welding temperatures can cause burnthrough.
- cast nickel alloy** An alloy containing nickel that has been poured as a liquid into a mold and cooled into a solid shape. Cast nickel alloys are often difficult to weld because of their high silicon content.
- cold working** The shaping of metal at temperatures substantially below the point of recrystallization. Cold working adds strength and hardness.
- compressive strength** A metal's ability to resist forces that attempt to squeeze or crush it.
- copper** A reddish metal that is very ductile, thermally and electrically conductive, and corrosive resistant. Copper is often used to make electrical wire.
- copper-lead alloy** An alloy containing copper and lead, which has the poorest weldability because the toxic lead often contaminates the weld.
- copper-tin alloy** An alloy containing copper and tin, which is the most weldable of the copper alloys. Tin adds strength and hardness to copper. Copper-tin alloys are also known as bronze.
- copper-zinc alloy** An alloy containing copper and zinc, which has poor weldability and tends to give off offensive fumes. Copper-zinc alloys are also known as brass.
- corrosion resistance** A metal's ability to resist attack by other elements and chemicals.
- cracking** A fracture that develops in the weld after solidification is complete. Welds with high hardness can cause cracking.
- ductility** A metal's ability to be drawn, stretched, or formed without breaking.
- electrical conductivity** A metal's ability to conduct an electrical current.
- electrode** A device that conducts electricity. In arc welding, the electrode also can act as the filler metal.
- ferrous metal** A metal that contains iron. Steel is the most popular ferrous metal.
- filler metal** A type of metal sometimes added to the joint in fusion welding. Filler metal adds to the strength and mass of the welded joint.
- galvanizing** The process of adding a zinc coating to steel. Galvanized steel is used to manufacture car parts, building frames, and ducting.
- gas torch** A device that emits heat in the form of a gas. Gas torches are used to preheat base metals.
- gauge** A standard of measure used to determine a specific thickness of sheet metal.
- grain structure** The relationship between the small, individual crystals in a metal or alloy.
- grinding** The use of an abrasive to wear away at the surface of a workpiece.
- hardness** A metal's ability to resist indentation, penetration, and scratching. The heat from welding may change a metal's hardness.
- heat treatment** The controlled heating and cooling processes used to change the structure of a material and alter its physical and mechanical properties.
- heat-affected zone** The portion of the base metal that has not been melted, but its mechanical properties have been altered by the heat of welding.
- heat-treatable alloy** Alloys that can be heated after welding to restore their strength properties.

joint	The meeting point of the two materials that are joined together. Welding creates a permanent joint.
lead	A soft, heavy, toxic metallic element. Lead is often used in gasoline.
magnesium	A grayish white, extremely light metal that is also brittle and has poor wear resistance.
mechanical properties	The properties that describe a material's ability to compress, stretch, bend, scratch, dent, or break.
melting temperature	The temperature necessary to change a metal from solid to a liquid. Also known as melting point.
nickel	A hard, malleable, silvery white metal used in various alloys to add strength, toughness, and impact resistance to metals.
nonferrous metal	A metal that does not contain iron. Aluminum and copper are common nonferrous metals.
nonheat-treatable alloy	Alloys that rely primarily on cold working to increase their strength properties.
physical properties	The properties that describe a metal's ability to melt, emit heat, conduct electricity, and expand or shrink.
post heating	The application of heat to the weld immediately after welding. Post heating helps reduce stress in the weld metal.
precipitate	The separation of elements from a type of solution. Elements that precipitate out of a solution change a metal's properties.
precipitation hardening	The process of heating to a temperature at which certain elements precipitate, forming a harder structure, and then cooling at a rate to prevent return to the original structure.
preheating	The application of heat to a base metal immediately before welding. Preheating helps reduce hardness in the metal.
properties	A characteristic of a material that distinguishes it from other materials.
recrystallization	The formation of a new grain structure. Recrystallization is often the result of annealing.
silicon	A nonmetallic element often found in sand and used to make glass. High amounts of silicon in a weld metal can cause cracking.
solution heat treating	A heat treatment method used to heat an alloy to a specific temperature for a certain period of time to allow one or more alloy elements to dissolve in a solid solution and then cool rapidly.
steel	A metal consisting of iron and carbon, usually with small amounts of other elements. Steel is the most common manufacturing metal.
strength	A metal's ability to resist outside forces that are trying to break or deform the metal.
supersaturated solution	A solution that is completely filled with alloying elements.
tack weld	A weld made to hold the parts of a weld in proper alignment before the final welds are made. Tack welds are also used to aid in preheating.
tensile strength	A metal's ability to resist forces that attempt to pull it apart or stretch it.
thermal conductivity	The rate at which heat flows through metal.
thermal expansion	The increase in the dimensions of a metal due to an increase in its temperature.
tin	A silver-white, soft metal used in many alloys. Tin is often used to coat other metals to prevent corrosion.
titanium	A silver-gray, strong, but lightweight metal known for its corrosion resistance. Titanium is often used in the aerospace industry.
toughness	A metal's ability to withstand a sharp blow.
weave	Movement of the electrode in a back and forth motion to deposit weld metal into a joint.
weld	A mix of metals that joins at least two separate parts. Welds can be produced by applying heat, or pressure, or both heat and pressure, and they may or may not use an additional filler metal.
weldability	The ability of a material to be welded under imposed conditions into a specific, suitable structure and to perform satisfactorily for its intended use.
wrought nickel alloy	An alloy containing nickel that has been bent, hammered, or physically formed into a desired shape. Wrought nickel alloys are often welded under the same conditions as certain types of steel.
yield strength	A metal's ability to resist gradual progressive force without permanent deformation.
zinc	A bluish white metal that is corrosive resistant and has a relatively low melting point. Zinc is often used as a coating on steel.