Material Science in Welding

Objective:

1. Define metallurgy terms.
2. Compare and contrast ferrous and nonferrous metals.
3. Describe three physical properties of metals.
4. Describe five mechanical properties of metals.
5. Compare and contrast different types of ferrous metals based on carbon content and uses.

Terms:

alloy: A material having metallic characteristics and made up of two or more elements, one of which is a metal.

brittleness: The tendency of a material to fail suddenly by breaking when stressed, without permanent deformation of the material before failure.

coefficient of thermal expansion/contraction: The ratio showing how much any dimension of a given material (including metal) changes as temperature changes (measurement of expansion and contraction per heat transfer). For example, when a material is heated, it either expands or contracts. The amount this occurs within a given temperature range is called the coefficient of expansion.

compressive strength: A metal's ability to resist forces that attempt to squeeze or crush it.

distortion: The undesired alteration of a part usually caused by mechanical or thermal means; may also be applied to wave forms.

ductility: The tendency of a material to physically deform under an applied mechanical stress.

electrical conductivity: The rate at which electric current will flow through the metal.

ferrite (Fe): Pure iron crystal structure.

ferrous metals: Metals that contain iron as the primary element. Ferrous metals are the most common type of welded metal.

hardness: The ability of a material to resist indentation, penetration, abrasion and/or scratching.

heat affected zone (HAZ): The portion of the base metal that has not been melted but whose mechanical properties have been altered by the heat of welding.

Terms Cont'd.:

magnetic: A material that can be attracted to magnets; magnetic forces can be used to weld workpieces together.

melting point: The temperature at which a solid becomes a liquid. Welding requires metals to reach their melting points.

modulus of elasticity: The ratio of tensile stress to the strain it causes, within that range or elasticity where there is a straight-line relationship between stress and strain. The higher the modulus, the lower the degree of elasticity.

nonferrous metal: A metal that does not contain iron. Nonferrous metals are more difficult to weld than ferrous metals.

shear strength: The ability of a material to withstand opposing forces.

specific heat: The quantity of heat necessary to raise a unit mass of a substance by one degree Celsius (1.8°F). If twice as much energy is added to a substance, its temperature should increase by twice as much. Specific heat is usually expressed in joules.

tensile strength: The ability of the metal to resist forces that attempt to pull it apart or stretch it. thermal conductivity: The rate at which heat flows through metal.

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.

torsional strength: The ability of a material to withstand twisting forces (torque).

yield strength: The ability of a metal to tolerate gradual progressive force without permanent deformation.

Introduction

We use a wide variety of metals, including steel, cast iron, aluminum and stainless steel, to build things. Not surprisingly, different metals react to the welding process in different ways. In addition, differences in their chemical properties make some metals more suitable than others are for specific applications. For example, some metals are excellent conductors of heat and electricity, some are used to coat other metals, and still others are used in the food industry. Welders must be very familiar with the wide range of properties of metals in order to create the best weld possible.

Types of Metal

There are two primary classifications of metals, *ferrous* and *nonferrous*.

Ferrous Metals: The primary element in ferrous metals is iron. Chemical terms for iron, such as the chemical symbol (Fe) and the names of iron compounds, come from the Latin word for iron, ferrum. *Ferrite* is the form of pure iron found at room temperature.

Nonferrous: The primary elements in nonferrous metals are not iron. Table 1 lists a variety of common nonferrous metals.

Table 1. Nonferrous Metals

1.	13 Aluminum Al 26.982	Lightweight, good conductor of heat and electricity
2.	29 Copper Cu 63.546	Excellent conductor of heat and electricity, resistant to corrosion
3.	12 Magnesium Mg 24.305	Lightweight, lighter than aluminum; used to build lightweight components to save energy; will burn violently and produces toxic magnesium oxide smoke.
4.	28 Nickel Ni 58.69	Used as an alloy with iron to produce nickel steel and stainless steel; produces tough, higher-strength materials.
5.	50 Tin Sn 118.71	Used in the food and agricultural industries to protect products as a coating or plating

Table 1, Cont'd. Nonferrous Metals

6.		Common use is to coat metallic materials like sheets of steel, to prevent corrosion (rust); galvanized steel has a zinc coating. Toxic to weld.
7.		Lightweight, high-strength metal; used to save energy by reducing material weight.

All ferrous metals are iron-based, and therefore it is common for these types of iron and steel to be strongly *magnetic*. However, nonferrous metals contain no iron, and therefore, most have very weak to no magnetic properties. Alloys are metals made of a combination of metals and other elements that substantially change their physical and mechanical properties. An example is stainless steel, an alloy made of iron, nickel and chromium.

Physical Properties of Metal

The physical properties of metals are characteristics observed when some form of energy changes the metal.

Examples of physical properties:

- Magnetic: having the tendency to react to magnetism; magnetic forces can be used to weld workpieces together.
- *Melting point*: the temperature at which metals transform from solid to liquid.
- *Thermal conductivity*: the rate at which heat moves through the metal; aluminum is a very good thermal conductor.
- *Electrical conductivity*: the rate at which electricity conducts through metal; copper is a very good conductor of electricity.

The physical properties of metals determine what applications suit different metals, and helps identify the various metals. These properties can also determine welding principles and practices.

Mechanical Properties of Metal

Mechanical properties refer to the characteristics of a metal that display when a force is applied to the material.

Examples of mechanical properties:

- *Tensile strength*: the ability of the metal to resist forces that attempt to pull it apart or stretch it. Material that supports a ceiling-mounted shop hoist would need good tensile strength.
- *Compressive strength*: a metal's ability to resist forces that attempt to squeeze or crush (compress) it. A steel support under a bridge would need to have good compressive strength.
- *Hardness*: the ability of a material to resist being indented and punctured. A bulldozer blade would need to be hard to resist damage from rocks and other objects.
- *Ductility*: the ability of metal to become permanently deformed without failure. Sheet metal for a fender needs to be ductile so it can be shaped.
- *Brittleness*: very nearly the opposite of ductility. The tendency of a material to fail suddenly by breaking when stressed, without permanent deformation of the material before failure. A shock absorber mount on a truck would need to lack brittleness. Brittleness is an undesirable mechanical property in most applications of various metals
- *Shear strength*: the ability of a material to withstand opposing forces. Bolts fastening two plates of metal together need to have good shear strength.
- *Torsional strength*: the ability of a material to withstand twisting forces (torque). A truck driveshaft or axle needs to have good torsional strength.

The ability of metals to resist or withstand these mechanical properties directly applies in determining the use of these metals. For example, an axle shaft needs to withstand twisting forces, so high torsional strength steel should be used.

Composition of Ferrous Metals

Steel is iron that has carbon and other alloys added to it to change the properties of the metal. Use of carbon increases the hardness and strength of steel. Table 2 describes the characteristics and properties of several types of iron-based materials.

Table 2. Composition Of Ferrous Metals		
Ferrous Metal	**% Carbon**	**Characteristics/Properties**
Wrought Iron	<0.003%	• Basically pure iron • Superior corrosion and fatigue resistance • Not many common uses, some furniture.
Low Carbon Steel	0.05% – 0.30%	• Also called “mild” steel • Relatively soft, ductile • Easily worked, formed, machined • Easily weldable • 0.05 – 0.15% C used for common types of nails, bolts, pipe and sheets for pressing and stamping • 0.15 – 0.30% C use for bars, plates and structural shapes for building projects.
Medium Carbon Steel	0.30% – 0.55%	• Moderate strength characteristics • Weldable • 0.30% – 0.40%C used for axles, connecting rods, shafting • 0.40 – 0.55%C used for crankshafts, rails, boilers
High Carbon Steel	0.55% – 0.80%	• Strong and hard • Does not bend • Can be heat treated • 0.55 – 0.70% C used for tools which are hammered, pounded • 0.70 – 0.80% C used for punches, drills, chisels, hammers, etc., • Difficult to weld
Very High Carbon Steel (Tool Steel)	0.80% –1.70%	• Very hard and strong (increases as % carbon increases) • Higher quality tools • Often has alloying metals added • Used for drills, files, knives, shear blades, metal cutting saws, etc. • Very difficult to weld
Cast Iron	1.8%– 4.3%	• Not considered a steel • Very hard, brittle; low bending strength, but can be heat treated • Used for machinery, engine, transmission housings • Some types are weldable but require special techniques such as pre – and post-heating

Classifications of Steel

The Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI) have developed a four-digit classification system for steels (see Figure 1):

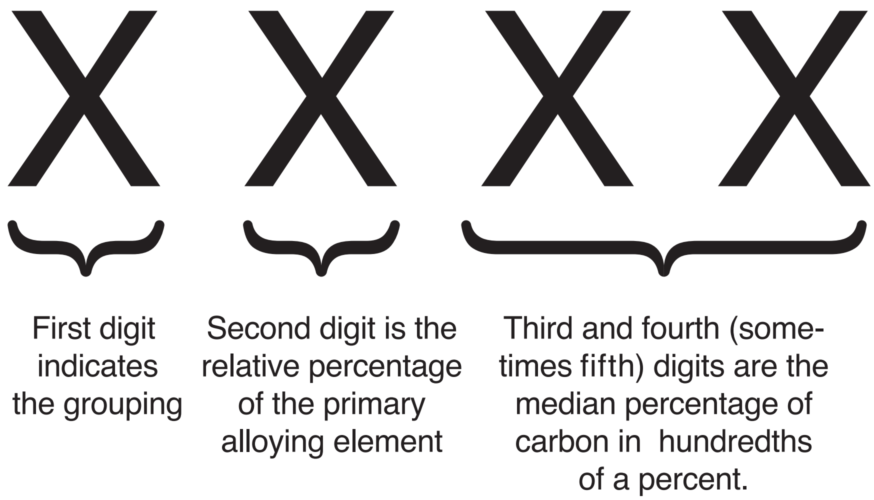

Figure 1. Classification Of Steel

The SAE groups of steels are:

- Carbon Steels 10XX and 11XX
- Manganese Steels 13XX and 15XX
- Nickel Steels 23XX and 25XX
- Nickel-Chromium Steels 31XX, 33XX
- Molybdenum Steels 40XX, 41XX, etc.
- Chromium Steels 51XX, 52XX
- Chromium-Vanadium Steel 61XX
- Multiple Alloy Steels 8XXX, 9XXX

Therefore, an AISI/SAE 1018 steel is a relatively pure carbon steel that has a 0.18% carbon content, making it a low carbon (mild) steel often used in shafts, pins, parts or agricultural equipment. An AISI/SAE 4130 steel is considered a “Chrome-Moly” steel with a 0.30% carbon content often used for bicycle frames, aircraft parts and welded tubing used in transportation of pressurized gas.

ASTM International

ASTM International is an international standards organization that sets standards for a variety of products, systems, materials and services. One of these materials is carbon steel. See Table 3 for carbon steel grade classifications.

Table 3. Carbon Steel Grade Classifications	
Designation	**Title**
A36	Carbon structural steel
A131	Structural steel for ships
A242	High-strength low-alloy structural steel
A283	Low and intermediate tensile strength carbon steel plates
A328	Steel sheet piling
A514	High-yield-strength, quenched, and tempered alloy steel plate, suitable for welding
A529	High-strength carbon-manganese steel of structural quality
A690	High-strength low-alloy nickel, copper, phosphorus steel H-piles and sheet piling with atmospheric corrosion resistance for use in marine environments

Distortion

Metals expand when heated and contract (shrink) upon cooling. *Distortion* occurs when a metal does not return to its original shape and/or position. Generally, you cannot stop distortion from occurring, but you can work with the metal to control it. Distortion is often a big challenge when fabricating a metal project.

During the heating and cooling cycle inherent in the welding process, *thermal expansion* of the weld metal and adjacent base material is not uniform. This produces stresses in the metals that cause distortion. The degree of distortion depends on the stresses generated. Several physical and mechanical properties of the welding metals affect how they expand and contract as they are heated and cooled. As the heat in a weld area increases, the *yield strength*, *modulus of elasticity* and thermal conductivity of steel all decrease, while its *coefficient of thermal expansion* and *specific heat* increase.

Heat Affected Zone

Figure 2 shows the areas affected by heat input during the welding process. As the illustration depicts, the *heat affected zone (HAZ)*, is an area in the base metal that, while not melted, still has had its properties altered by the heat of welding. The high temperatures from the welding process followed by re-cooling causes this change, which extends outward from the weld interface. These areas can vary in size and levels of intensity and tend to cause a reduction in the strength of the material through the zone.

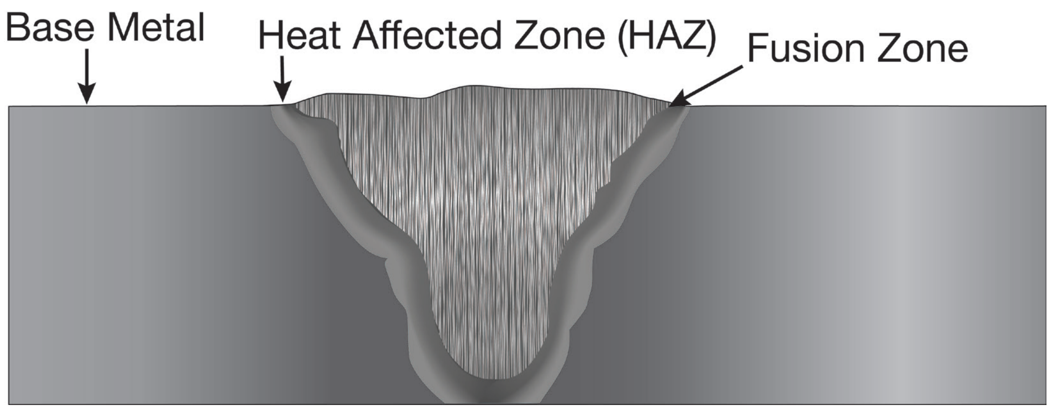

Figure 2. Heat Affected Zone

Conclusion

The wide range of properties of metals makes them quite versatile. For instance:

- A less-malleable metal would be necessary for a construction tool.
- Metals with more luster are ideal for jewelry.
- Cookware requires a metal that is a good conductor of heat.

Knowing at least the most basic properties of metals, as well as how different metals react to the welding process allows welders to make quality welds.