Metallurgy for the Non-Metallurgist™

Metals and alloys are used in the greatest variety of applications of all engineering materials. As such it is essential for those involved in manufacturing, engineering and construction to have an understanding of what metals are, how they behave, and why they behave differently than ceramics, glass, and plastics. It is also important to understand how they can be made stronger or more corrosion resistant, how they can be shaped by casting, forging, forming, machining, or welding, and how these processes can alter properties. This course provides this important knowledge to those who are not metallurgists.

WHO SHOULD ATTEND?
- Metal Processing Personnel
- Machine Shop Superintendents
- QA Managers
- Heat Treating Operators and Managers
- Component Designers
- Technicians
- Marketing, Technical Writers, and individuals without a materials background wishing to better understand the role of materials science

LEARNING OBJECTIVES
Upon completion of this course, you should be able to:
- Describe how metals and behave, and why; including why and how they can be formed
- Recognize how metals can be strengthened by alloying, cold-working, and heat treatment
- Determine why metals and alloys are not behaving as expected and can be made to behave as needed
- Choose what metal or alloy to use for specific combinations of properties

COURSE OUTLINE
1. Metals
2. Extractive Metallurgy
3. Solidification of Metals
4. Metal Forming
5. Mechanical Properties and Their Measurement
6. Steels and Cast Irons: Applications and Metallurgy
7. Heat Treatment of Steel
8. Case Hardening of Steel
9. Strengthening Mechanisms
10. Nonferrous Metals
11. Joining
12. Corrosion and Corrosion Prevention
13. Quality Control and Failure Analysis
14. Materials Characterization and the Selection Process

Continuing Education Units: 3.0
Detailed Course Outline / Learning Objectives

Lesson 1: The History of Metals

There are no non-metallurgists in the modern world. We long since passed from the Stone Age through the Bronze and Iron Ages in to a modern developed society—a society that is dependent on metals and alloys for its very existence. Cars, trucks, airplanes, buildings, bridges, computers, electric power, telephones, refrigerators, cook wear and even decorative items such as jewelry cannot exist without metals. Because of the importance of metals to our society, no one can escape being a metallurgist. We make metallurgical choices almost daily. Thus, regardless of where we work, where we live and how we play, metallurgy has a significant role in our life. This course provides the basis for making informed metallurgical choices. These choices may involve your vocation, but regardless of your vocation, the choices will involve your life. To paraphrase an old slogan, this course will build a foundation for “Better Things for Better Living through Metallurgy.”

Upon completion of this lesson the learner can:

- Summarize the history of metallurgy from ancient to modern times.
- Define such terms as metal, ore, alloy, refining, and smelting.
- Outline the relative availability of specific metals.

Lesson 2: Extractive Metallurgy

Extractive metallurgy begins after the ore deposit is found and the mineral rights obtained and economic analysis completed. Recall the actions of the old prospectors. They search for an ore deposit that contains a lot of gold. After they find the gold, they stake or file their claim, and then they begin to work the claim. Today’s prospectors work for corporations, use very sophisticated analytical tools and employ multidisciplinary teams to assure economic success. The job of the extractive metallurgist is to mine the ore deposit, concentrate the portions of the deposit that have a high metal content, and then extract the metal from the minerals that were naturally formed by the reaction between the metal and oxygen or sulfur, or some other nonmetallic element. This lesson describes several techniques for concentrating the ores and extracting the metal from concentrated minerals. The techniques described are not new but were selected because they provide a fundamental basis to understand extractive metallurgy.

Upon completion of this lesson, the learner can:

- List several methods for concentration of ores and discuss these methods in regard to the techniques for mineral processing.
- Define hydro-, pyro-, and electrometallurgy and discuss this as simple techniques to provide the energy necessary for extraction of metals from metallic ores.
- Describe the processes of oxidation and reduction and understand that oxidation of metals is a naturally occurring process.
- Outline the steps in production of pig iron and steel.
Lesson 3: Solidification of Metals

This lesson introduces basic concepts of the characteristics of atom arrangements which provide the crystal structure of metals describes the solidification process and introduces phase diagrams. Phase diagrams provide a graphical description of what happens to a metal when two metals are melted together and solidified as an alloy. In the diagram temperature is important because the alloy may change from a crystalline (solid) phase to a liquid phase as the temperature increases. The relative amount of the two metals is also important because the crystal structure may change as the composition changes.

After completing this lesson, the learner can:

- Describe the basic metal crystal structures
- Explain the process of solidification in metals
- Read a basic binary phase diagram

Lesson 4: Metal Forming

The role of metal forming is to convert an ingot or some other metallic form into a product that can be used by a manufacturing or construction engineer, a homemaker, a shop mechanic, or any person needing the product. There are several basic routes by which refined metals and alloys may be formed into useful products. The main routes are casting, wrought technologies, and powder metallurgy.

After completing this lesson, the learner can:

- Discuss the principles of major forming processes
- Discern the effect that processing technology has on a finished part
- Be aware of the importance of processing variables
- Recognize potential processing defects

Lesson 5: Mechanical Properties

Terms such as strength, ductility, hardness, toughness and wear resistance are used to describe the response of metals and alloys under certain situations. These terms are associated with the results of mechanical tests used to measure the response of metals to forces that they may be required to support. This lesson introduces several of the mechanical tests used to characterize metals and alloys.

After completing this lesson, learners can:

- Outline the procedures for performing tensile and hardness tests
- List the three categories of properties measured by the tensile test
- Describe a fatigue test in general terms
- Define yield and ultimate strengths, elongation in 2 in., impact toughness, creep rate, and fatigue endurance limits
Lesson 6: Steels and Cast Irons

Two alloys of iron, steel and cast iron, are familiar to almost everyone. We cook in cast iron pots and pans (or at least our grandmothers did) and our automobile frames are made of steel. The bases for large machines are often cast iron and the bolts we use to fasten things together are often steel. These materials are very different from each other in spite of their common base element. The range of properties available in each type of alloy is extremely variable. Some cast irons are malleable (can be shaped by plastic deformation) while others are brittle and fracture relatively easily. The strength of steels can vary from slightly below 30,000 psi to in excess of 150,000 psi. It is this diversity of attainable properties that makes cast irons and steels useful to society.

Upon completion of this lesson, the learner can:

- Describe steel
- List some of the properties of steel and explain how they are different from other materials
- Tell how steel is produced
- Describe cast irons
- Tell how cast iron differs from steel

Lesson 7: Heat Treatment

Heat treatment is not unique to steels or even to metallic materials. Cooking can be described as the heat treatment of foods where the food is exposed to a variety of thermal conditions designed to produce a desired result (taste, texture and nutrition). Clay pots are heat treated to harden and provide strength to the clay and make pot useful. The process of heat treating metals and metal alloys is simply the heating and/or cooling a solid metal or alloy in a way designed to produce specific conditions and/or properties. Heat treatments are generally entirely thermal and simply modify a metal’s microstructure without significantly changing the shape or dimensions of the component. Processes that alter the metal’s shape and structure, such as thermomechanical or thermochemical treatments, fall into the domain of heat treating, but these techniques are not addressed in detail in this lesson.

After completing this lesson, learners can:

- Describe the austenite transformation processes
- List the primary quenching media and their applications
- Explain tempering
- Classify heat treating furnaces by heat transfer media
- Outline the procedure for the Jominy end-quench test for hardenability
Lesson 8: Case Hardening of Steel

Case hardening is the process of producing a hard, wear-resisting surface on a softer, tough steel core. Many fruits and vegetables naturally produce a case (peeling) that has properties that differ significantly from the underlying core. Bread has a crust and the properties of the crust are controlled by the baking practices, including baking time, temperature and environment. In a similar fashion, the properties of the outer surface of a steel component can be modified by surface hardening the component under appropriate conditions. In many metallurgical applications, strength is of minor importance and wear resistance is the major consideration. In such cases, the center condition of the steel is relatively unimportant as long as the wearing surface is hard and wear resistant. In other applications where wear resistance is still the prime consideration, a high level of strength and considerable toughness are also required. In such cases, a hard-wearing surface backed up by a strong and tough core is necessary.

After completing this lesson, learners can:

- List the reasons for case hardening
- Outline the advantages of carburizing, carbonitriding, nitriding, and induction surface hardening
- Describe in general the operation of batch-type and continuous furnaces
- Compare surface hardening by induction to other processes
- Give the reasons for quenching of case-hardened parts
- Differentiate between effective case depth and total case depth

Lesson 9: Strengthening Mechanisms

The Bronze Age represents the time in history when the early metallurgists recognized that copper could be significantly strengthened by alloying the copper with tin. The metallurgists already knew that copper could be strengthened by cold working but the idea that metals could be strengthened by alloying was so significant that the term Bronze Age is used to recognize the development of this understanding. Most of the nonferrous metals cannot be hardened to a significant degree by the techniques used for hardening steels because most other metals and alloys do not undergo martensitic transformations. However, the mechanical properties of most metals can be improved by cold working, alloying or by other heat treating processes.

After completing this lesson, learners can:

- Describe the effects of alloying elements on the strength of metals
- Define age (precipitation) hardening
- Define cold working and annealing
- Explain the optimal strengthening mechanisms for several group of alloys
Lesson 10: Nonferrous Metals

A survey of industrially significant nonferrous metals demonstrates that the significance of any group of metals and alloys depends on the industry being surveyed. Precious metals such as gold, silver and platinum are significant to the jewelry industry. High conductivity, corrosion resistant metals are important to the electronics industry and high strength, light weight alloys are significant to the aerospace automobile and airplane industries. Basically, the significance of any metal or alloy depends on at least three factors: cost, properties and demand. These three factors are interrelated through complex interactions that are easy to describe but, at best, difficult to fully understand.

Upon completion of this lesson, the learner can:

- List the significant properties of aluminum, beryllium, magnesium, titanium, copper, lead, tin, and zinc
- Describe the primary applications for several nonferrous metals and alloys
- Identify the precious metals and outline some of their principal applications

Lesson 11: Joining

The assembly of most engineered systems requires that various parts and components be attached or joined to each other. There are five general categories of joining techniques: welding, brazing, soldering, adhesive bonding, and mechanical joining. Welding, brazing and soldering are metallurgical processes and are the three joining technologies discussed in this lesson. Welding generally involves localized melting of the components being joined while the component is not melted during brazing or soldering.

After completing this lesson, learners can:

- Define the terms, welding, brazing, and soldering
- Describe the basic principles of arc welding, electroslag welding, oxyfuel gas welding, and resistance welding processes
- List some of the principal applications of brazing processes
- Describe the principles of soldering processes and their applications
Lesson 12: Corrosion

Corrosion is an electrochemical process that naturally occurs when metals and alloys are exposed to oxidizing environments. Most metals used today were originally metallic ores in the earth’s crust and were converted to metals and alloys by extractive metallurgy processes. The fact that the metallic elements in the earth’s crust originally existed as metallic ores demonstrates that earth’s environment is naturally aggressive to metallic elements and that after the element has been refined continue exposure to the environment will return the metal to an ore like form. Corrosion is one of the primary ways that the environment interacts with metals and alloys to produce the ore-like form.

After completing this lesson, learners can:

- Describe the principal types of corrosion including: uniform, galvanic, concentration cell, pitting, selective leaching, intergranular, erosion, and crevice corrosion
- Explain the significance of the galvanic series in corrosion analysis and prevention
- List the ways to prevent or to minimize corrosion

Lesson 13: Quality Control

A primary objective of manufacturing processes is to assure customer satisfaction with the product. This is true for consumer products such as an automobile, a tractor, or a razor blade and for commercial products, such as an airplane, an extrusion press or a communications satellite. Product quality is inescapably linked to customer satisfaction and quality control is necessary to assure product quality. Engineering teamwork creates the kind of reliability that provides quality assurance and a product with an advantage over its competitor. Manufacturing processes demand close control and modern manufacturing practices use instruments designed to provide necessary information quickly and accurately to operators, including operators who have no knowledge of the physical principles that underlie the manufacturing process. The same is true of many of the instruments designed for testing materials for flaws, for chemical composition, or for physical structure. Basically, the information required to assure proper control of many manufacturing processes is used by the operator in a fashion similar to the use of the television controls. The operations of the TV set can be successfully modified (channel changed, volume increased, etc.) even though the TV operator has no knowledge of how the set works.

After completing this lesson, the learner can:

- Define quality control
- Describe five primary nondestructive inspection tests
- List the important steps of a failure investigation
- Explain statistical quality control methods
- Outline sampling procedure for quality control
Lesson 14: Materials Characterization

The design of material components is a complex engineering task requiring consideration of many interrelated factors and unfortunately not all of the factors are necessarily compatible. Compromises and tradeoffs among various design variables are routinely made and factors that are important in one system may be insignificant in another. A designer must know the relative importance of design variables, including materials selection, and must understand the factors that impact material performance before intelligent choices between conflicting requirements can be made. These choices may require selecting a material that can only meet one of two conflicting requirements and may even force a design change.

After completing this lesson, the learner can:

- List the main categories of material properties that must be considered in design
- Summarize the service requirements that affect material selection
- Describe the material selection process
- List the resources available to aid in the material selection process