SUBCOURSE
OD1643

EDITION
7

METAL PROPERTIES, CHARACTERISTICS, USES, AND CODES

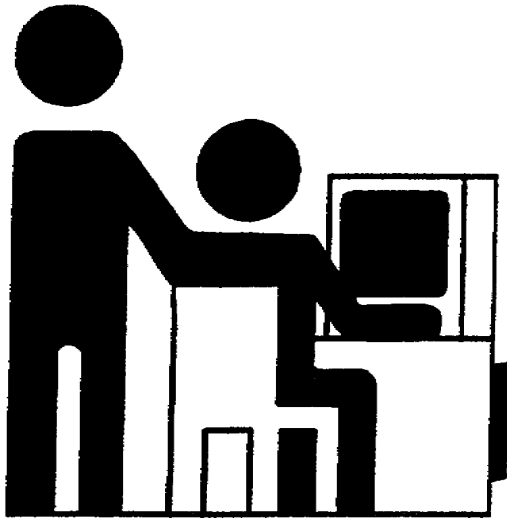
AIPD

READINESS/
PROFESSIONALISM

THRU
GROWTH

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM



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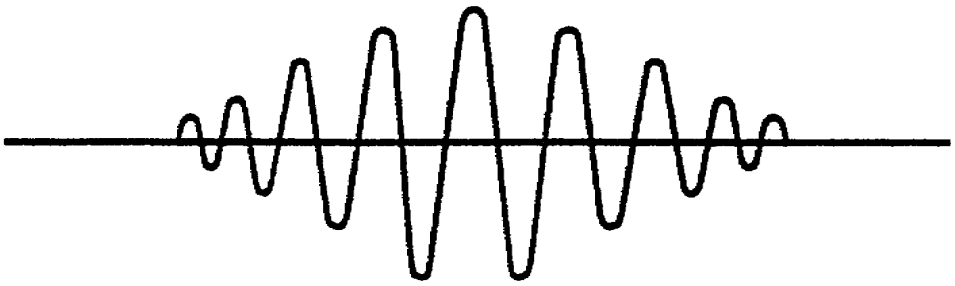

US ARMY REPAIR SHOP TECHNICIAN WARRANT
OFFICER ADVANCED CORRESPONDENCE COURSE

MOS/SKILL LEVEL: 441A

METAL PROPERTIES, CHARACTERISTICS, USES, AND CODES

SUBCOURSE NO. OD1643

US Army Correspondence
Course Program

6 Credit Hours

GENERAL

The purpose of this subcourse is to introduce the student to the properties of metals, their characteristics, uses and identification codes.

The subcourse provides descriptions of the processes for identifying the physical and mechanical properties, categories of various metals, and the processes for using the hardness tester, chemical analysis, bench grinder, simple shop tests, the numerical index system, and the color code for identifying various metals.

Six credit hours are awarded for successful completion of this subcourse.

Lesson 1: THE PHYSICAL AND MECHANICAL PROPERTIES OF VARIOUS METALS, AND USE OF THE HARDNESS TESTER, CHEMICAL ANALYSIS, AND BENCH GRINDER TO IDENTIFY VARIOUS METALS

TASK 1: Describe the processes for identifying the physical and mechanical properties of various metals.

TASK 2: Describe the processes for using the hardness tester, chemical analysis, and bench grinder to identify various metals.

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LESSON 1

THE PHYSICAL AND MECHANICAL PROPERTIES OF VARIOUS METALS, AND USE OF THE HARDNESS TESTER, CHEMICAL ANALYSIS, AND BENCH GRINDER TO IDENTIFY VARIOUS METALS

TASK 1. Describe the processes for identifying the physical and mechanical properties of various metals.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within three hours

REFERENCES

No supplementary references are needed for this task.

1. Introduction

Most of the metals and alloys used in Army materiel can be either welded or machined. Repair part components, such as gears, shafts, and wheel vehicle body and tank hull components, can be repaired or fabricated. Repair or fabrication involves the employment of the various welding or machining processes available to intermediate direct support (IDS) and intermediate general support (IGS) maintenance units in the field.

Hardware items such as nuts, bolts, screws, pins, and fuel line fittings can be machine fabricated, however, repair parts such as these are not always readily available in a combat situation. Further, such items as jigs and devices used in the repair of materiel are not stocked in the supply system. To compensate for these situations, IDS and IGS maintenance units in the field carry a supply stock of various metals from which to fabricate and/or

repair hardware, repair parts, jigs, and devices. But determining the type of welding or machining process needed to repair or fabricate these metal component parts, jigs, and devices requires knowledge of the properties, characteristics, uses and identification codes of metals.

The responsibility of ensuring that the personnel are trained, and of providing them with the capability to identify the various metals belongs to the shop technician in charge of the service section. For this purpose, the following paragraphs describe the processes for identifying the physical and mechanical properties of various metals.

2. Identification of Physical and Mechanical Properties of Various Metals

a. *General*. The distinguishing characteristics or qualities that are used to describe a substance such as metal are known as its physical properties. Those physical properties which describe the behavior of a metal when it is subjected to particular types of mechanical usage are called mechanical properties.

Subsequent paragraphs describe the physical and mechanical properties of metals. The mechanical properties are of chief concern and will therefore receive greater coverage.

b. *Definition of Metal and Alloy*.

(1) Before going into a discussion of the properties of metals, first let us define the terms "metal" and "alloy". The basic chemical elements are divided into metals and nonmetals; however, there is no sharp dividing line between the two. A metal may be defined as a chemical element that possesses metallic luster and which, in electrolysis, carries a positive charge that is liberated at the cathode. Most nonmetallic elements do not possess metallic luster, and in electrolysis the nonmetals carry negative charges that are liberated at the anode. Of all the natural chemical elements, about 70 are metals and, of these, about 39 are used commercially.

(2) An alloy is a metallic substance, but it is not a single chemical element. An alloy is formed by the union or mixture of two or more metals; in

some cases, it may consist of one or more metals and a nonmetal. Examples of alloys are iron and carbon, forming steel, and the great variety of copper alloys, such as brass and bronze.

c. *Physical Properties*. These properties are related to the atomic structure and density of the material, as described in the following paragraphs.

(1) *Co-efficient of Linear Expansion*. The co-efficient of linear expansion is the increase in length of a body for a given rise in temperature. The increase is the changed length of a rod for each degree that the temperature is increased. Metal expands when heated and contracts when cooled. It increases not only in length, but also in breath and thickness. The increase in unit length when a solid is heated one degree is called the co-efficient of linear expansion.

(2) *Heat and Electrical Conductivity*. Heat and electrical conductivity is the ability of a material to conduct or transfer heat or electricity.

(3) *Magnetic Susceptibility*. Magnetic susceptibility is the ability of a material to hold a magnetic field when it is magnetized.

(4) *Reflectivity*. Reflectivity is the ability of a material to reflect light or heat.

(5) *Specific Gravity*. Specific gravity is the ratio of weights between two objects of equal volume, one of which is water.

(6) *Melting Point*. The melting point is the temperature at which a substance passes from a solid state to a liquid state.

d. *Mechanical Properties*.

(1) *Strength*. The strength of a material is the property of resistance to external loads or stresses while not causing structural damage. Ultimate strength is the unit stress, measured in pounds per square inch, developed in the material by the maximum slowly applied load that the material can resist without rupturing in a tensile test. The strength of metals and alloys depends upon two factors: the strength of the crystals of which the metals are constructed, and the tenacity of adherence between these crystals. The strongest

substance known is tungsten-molybdenum; titanium and nickel follow in order of strength of commercially pure metals. Pure iron is much weaker, but, when alloyed with the chemical element known as “carbon" to make steel, it may then become stronger than any of the pure metals except tungsten. Strength and plasticity (discussed in paragraph 2d(6) on page 6) are considered the two most important properties that a metal can possess.

(a) *Tensile Strength*. Tensile strength is the ability of a metal to resist being pulled apart by opposing forces acting in a straight line (figure 1, view A, on the following page). It is expressed as the number of pounds of force required to pull apart a bar of material 1 inch wide and 1 inch thick. The tensile test is the one most often used to measure the strength of metals. Pure molybdenum has a high tensile strength and is very resistant to heat. It is used principally as an alloying agent in steel to increase strength, hardenability, and resistance to heat.

(b) *Shear Strength*. Shear strength is the ability of a material to resist being fractured by opposing forces acting in a straight line but not in the same plane (figure 1, view B, on the following page).

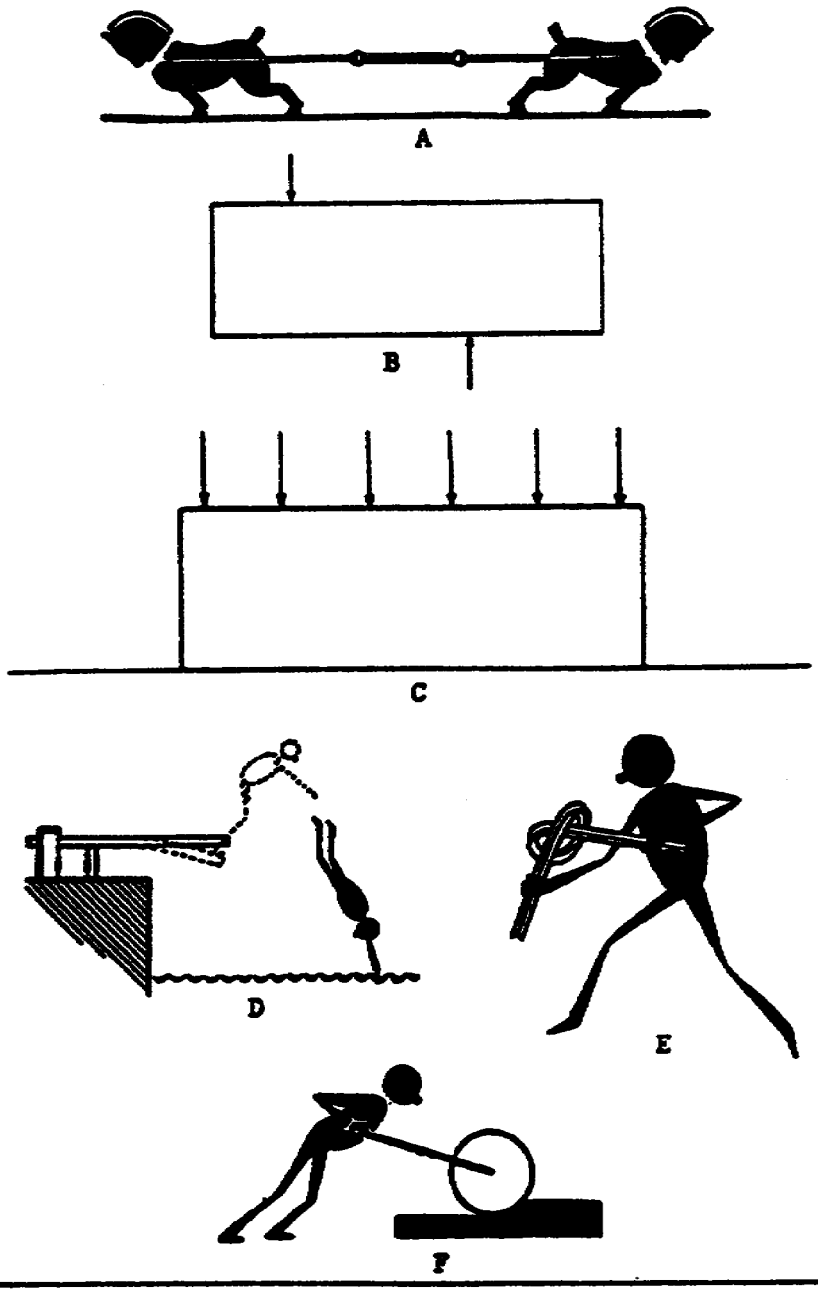
(c) *Compressive Strength*. Compressive strength is the ability of a material to withstand pressures acting on a given plane (figure 1, view C, on the following page).

(2) *Elasticity*. Elasticity is the ability of material to return to its original size, shape, and dimensions after being deformed (figure 1, view D, on the following page). Any material that is subjected to an external load is distorted or strained. Elastically stressed materials return to their original dimensions when the load is released, provided that the load is not too great. Distortion or deformation is in proportion to the amount of the load, up to a certain point. If the load is too great, the material is permanently deformed, and, when the load is further increased, the material will break. The property of regaining the original dimensions upon removal of the external load is known as elasticity.

(a) The elastic limit is the point at which permanent deformation begins.

(b) The yield point is the point at which a definite deformation occurs with little or no increase in load.

FIGURE 1. TENSILE, SHEAR, AND COMPRESSIVE STRENGTH; MALLEABILITY; ELASTICITY; AND DUCTILITY.



(c) The yield strength is the number of pounds per square inch required to produce deformation to the yield point.

(3) *Modulus of Elasticity*. The modulus of elasticity is the ratio of the internal stress to the strain produced. It expresses the stiffness of a material. For steel and most metals, this is a constant property and is affected very little by heat treatment, hot or cold working, or the actual ultimate strength of the metal. According to Hooke's Law: "The degree to which an elastic body bends or stretches out of shape is in direct proportion to the force (stress) acting upon it." But, this law only applies within a certain range.

(4) *Ductility*. Ductility is the capacity of a material, such as copper, to be drawn or stretched under tension loading and permanently deformed without rupture or fracture. Specifically, the term denotes the capacity to be drawn from a larger to a smaller diameter of wire. This operation involves both elongation and reduction of area (figure 1, view E, on the following page).

(5) *Malleability*. Malleability is the property of a metal to be deformed or compressed permanently without rupture or fracture. Specifically, it means the capacity to be rolled (figure 1, view F, on the following page) or hammered into thin sheets. The property of malleability is similar to but not the same as that of ductility, and different metals do not possess the two properties in the same degree. Lead and tin are relatively high in order of malleability; however, they lack the necessary tensile strength to be drawn into fine wire. Most metals have increased malleability and ductility at higher temperatures. For example, iron and nickel are very malleable when heated bright-red.

(6) *Plasticity*. Plasticity is the ability of a metal, such as gold, silver, or lead, to be deformed extensively without rupture. This property, together with strength, are considered to be the two most important properties that a metal can possess.

(7) *Toughness*. Toughness is a combination of high strength and medium ductility. Toughness is the ability of a material or metal to resist fracture, plus the ability to resist failure after

the damage has begun. In short, a tough metal, such as a cold chisel, is one that can withstand considerable stress, slowly or suddenly applied, and that will deform before failure. Toughness has been defined by some metallurgists as having the property of absorbing considerable energy before fracture and, therefore, involves both ductility and strength. Toughness is a measure of the total energy-absorbing capacity of the material, including the energy of both elastic and plastic deformation under a gradually applied load. Generally speaking, toughness applies to both strength and plasticity. Thus, a very easily deformed substance of low strength would not be considered tough, nor would a material of high strength, but with little plasticity, such as hardened tool steel. The true tough metal is one that will rapidly distribute within itself both the stress and resulting strain caused by a rapidly applied load.

(8) *Brittleness*. The term "brittleness" implies sudden failure. It is the property of breaking without warning; that is, without visible permanent deformation. It is the reverse of toughness in the sense that a brittle piece of metal has little resistance to rupture after it reaches its elastic limit. Brittleness can also be said to be the opposite of ductility, in the sense that it involves rupture with very little deformation. In many cases, hard metals are brittle; however, the terms should not be confused or used synonymously.

(9) *Corrosive Resistance*. Corrosive resistance is the resistance to eating away or wearing by the atmosphere, moisture, or other agents, such as acid.

(10) *Abrasion Resistance*. Abrasion resistance is the resistance to wearing by friction.

(11) *Fatigue*. When metal is subject to frequent repetitions of a stress, it will ultimately rupture and fail, even though the stress may not be sufficient to produce permanent deformation if continuously applied for a relatively brief time. Such a repetition of stress may occur, for example, in the shank of a rock drill. Alternation of stress will produce failure more rapidly than repetition of stress. Alternations of stress mean the alternate tension and compression on any material. The definition of fatigue is the failure of metals and alloys that have been subjected to

repeated or alternating stresses too small to produce a permanent deformation when applied statically.

(12) *Corrosion Fatigue*. Failure by corrosion fatigue is a fatigue failure in which corrosion has lowered the endurance limit by the formation of pits which act as centers for the development of fatigue cracks. Moreover, when any protective film that has been placed on the metal is broken by fatigue stresses, corrosion spreads through the cracks in the film and produces pits which act as stress raisers. If a metal member exposed to fatigue is also exposed to corrosive agencies, such as a damp atmosphere or oil that has not been freed from acid, the stress necessary to cause failure is lowered. It is interesting to note that the unit stress of an extremely strong heat-treated alloy steel that is subjected to corrosion fatigue will be no greater than that of a relatively weak structural steel. The importance of protecting the surfaces of fatigue members against corrosion by galvanizing, plating, etc., is obvious.

(13) *Machinability*. Machinability is the ease or difficulty with which a material lends itself to being machined.

(14) *Hardness*. Hardness is the ability of a material to resist penetration and wear by another material. It takes a combination of hardness and toughness to withstand heavy pounding. The hardness of a metal is directly related to its machinability, since toughness decreases as hardness increases.

Steel can be hardened by heat-treating it. The object of heat-treating steel is to make the steel better suited, structurally and physically, for some specific application. If additional information pertaining to heat-treatment of steel is desired, see TM 9-237 and FM 9-24.

3. Categories of Metals

a. *General*. All metals fall within one of two categories. Either they contain iron and are considered ferrous metals, or they contain no iron and are considered nonferrous metals.

b. *Characteristics of Steel and Cast Iron*.

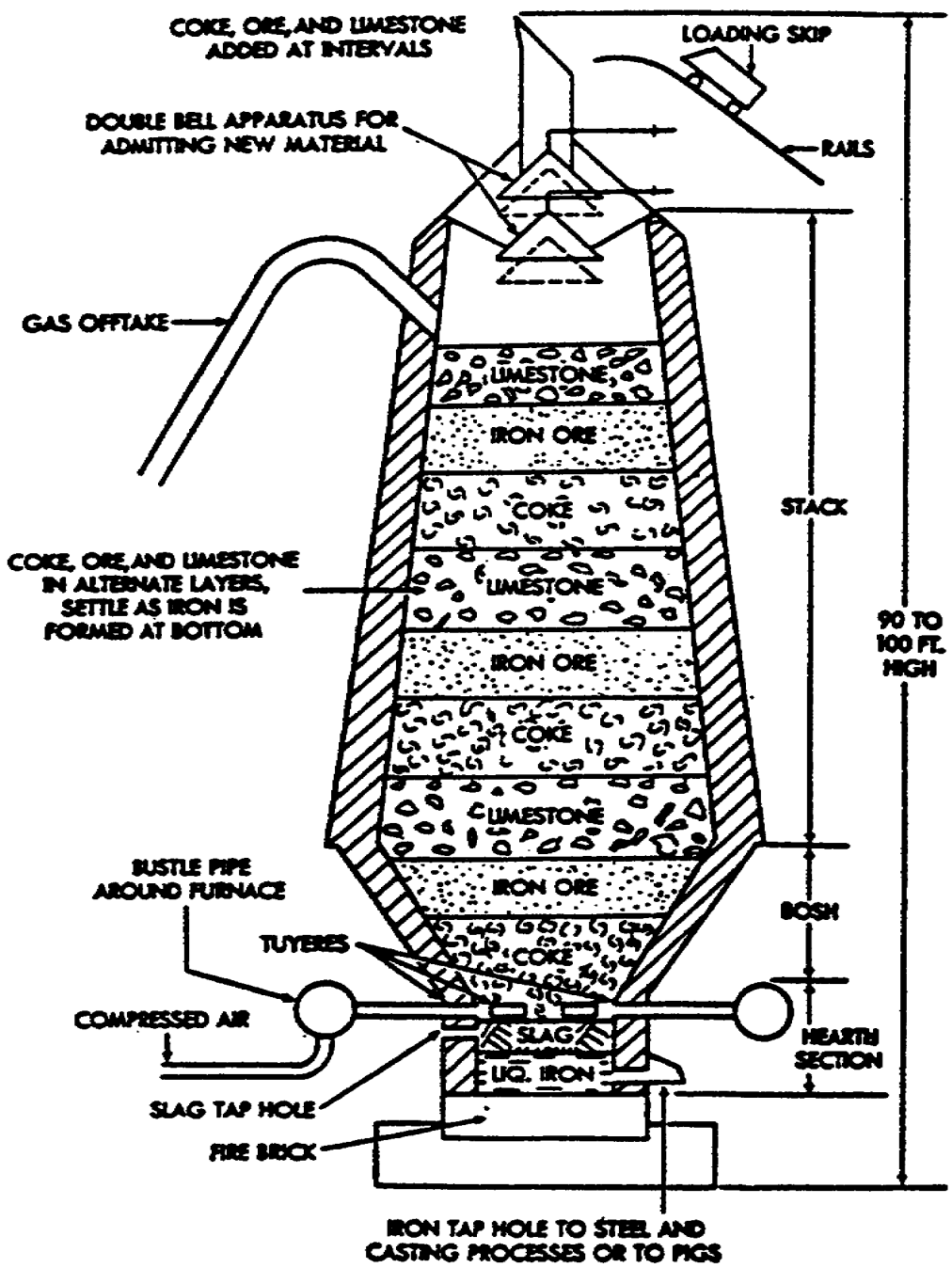
(1) *Basic Substance*. The basic substance used to make both steel and cast iron (gray and malleable) is the metal, iron in the form of pig iron. Pig iron is produced from iron ore, which occurs chiefly in nature as an oxide, the two most important oxides being hematite and magnetite.

(2) *Iron Ore*. Iron ore is reduced to pig iron in a blast furnace, and the impurities are removed in the form of slag (figure 2 on the following page). Raw materials charged into the furnace include iron ore, coke, and limestone. The pig iron produced is used to manufacture steel or cast iron. To convert iron ore to iron, the iron ore is smelted with coke and limestone in a blast furnace (figure 3 on page 13) to remove from it the oxygen (the process of reduction) and earth foreign matter. Limestone is used to combine with the earth matter to form a liquid slag; coke is used to supply the chemical element of carbon needed for the reduction and carburization of the ore. The iron ore, limestone, and coke are charged into the top of the furnace. Rapid combustion, with a blast of preheated air into the smelter, causes a chemical reaction in which the oxygen is removed from the iron. The iron melts, and the molten slag, consisting of limestone flux and ash from coke, together with compounds formed by the reaction of the flux with substances present in the ore, floats on the heavier iron liquid. Each material is then separately drawn off.

(3) *Plain Carbon Steel*. Plain carbon steel consists of iron and carbon, the latter being the hardening element. Tougher alloy steel contains other elements, such as chromium, nickel, and molybdenum. Cast iron is nothing more than basic carbon steel with more carbon added together with silicon. The carbon content range for steel is 0.03 to 1.7 percent, and for cast iron 4.5 percent.

(4) *Steel*. Steel is produced in a variety of melting furnaces: open-hearth, Bessemer converter, crucible electric-arc, and induction. Most carbon steel is made in open-hearth furnaces, while alloy steel is melted in electric-arc and induction furnaces. Steel, often considered as the master metal, is available in large quantities in both

FIGURE 2. BLAST FURNACE.



wrought and cast form. Because of its plasticity, steel may be worked at room temperature or at elevated temperatures.

It is possible, by varying the carbon content and by proper heat treatments, to alter properties from a very soft, workable steel, of the type used in pressed metal parts, wire, and similar materials, to hard, strong steel, suitable for use in tools, machinery, and armor, where great strength and hardness are necessary.

(5) *Cast Iron*. Cast iron is produced by melting a certain quantity or charge of pig iron, limestone, and coke in a cupola furnace. It is then poured into sand or alloy steel molds, and allowed to cool at room temperature. Cast iron is basically an alloy whose chief elements are iron, silicon, and carbon. The material is available with a wide range of properties. Pig iron, gray cast iron, white cast iron, chilled cast iron, and malleable cast iron are all referred to as cast iron.

(6) *Wrought Iron*. This is the oldest form of iron made by man. It is a metal that contains high purity iron and iron silicate. It is very low in carbon with the iron silicate or slag distributed throughout the base metal in fibers. These fibers give the material a woody or stringy appearance when broken.

(7) *Differences Between Cast Irons and Steels*.

(a) All the various forms of cast iron, steel, and wrought iron consist of chemical compounds and mixtures of iron, carbon, and various other elements in small quantities. Whether the metal is classified as cast iron or as one of the steels depends entirely upon the amount of carbon in it. The following table illustrates this principle:

Item	*Percent Carbon*	*Incorporated Carbon*
Pig iron	4.0	Free and combined
White cast iron	3.5	Mostly combined
Gray cast iron	2.5 to 4.5	0.6 to 0.9 percent free
Malleable cast iron	2.0 to 3.5	Free and combined
Tool steel	0.9 to 1.7	All combined
High-carbon	0.5 to 0.9	All combined
Medium-carbon steel	0.3 to 0.5	All combined
Cast steel	0.15 to 0.6	All combined
Low-carbon steel	up to 0.3	All combined

(b) Cast iron differs from steel principally because its excess of carbon (exceeding 1.7 percent) is precipitated throughout the matrix as flakes of graphite, which cause most of the remaining carbon to also precipitate. These particles of graphite form the paths through which failures occur and are the reason why cast iron is brittle. By carefully controlling the silicon content and the rate of cooling of cast iron, it is possible to cause any specified amount of the carbon to precipitate as graphite or to remain combined. Thus, we have white, gray, and malleable cast iron, all produced from similar base metals.

c. *Ferrous Metals*.

(1) *Wrought Iron*. Wrought iron is almost pure iron. In the process of manufacture, some slag is mixed with iron to form a fibrous structure in which long stringers of slag are mixed with long threads of iron. Because of the presence of slag, wrought iron resists corrosion and oxidation. It can be gas or arc welded, machined or plated, and is easily formed. However, wrought iron has low hardness and low fatigue strength.

(a) *Uses*. Wrought iron is used to make such items as architectural railings, farm implements, and modern household furniture.

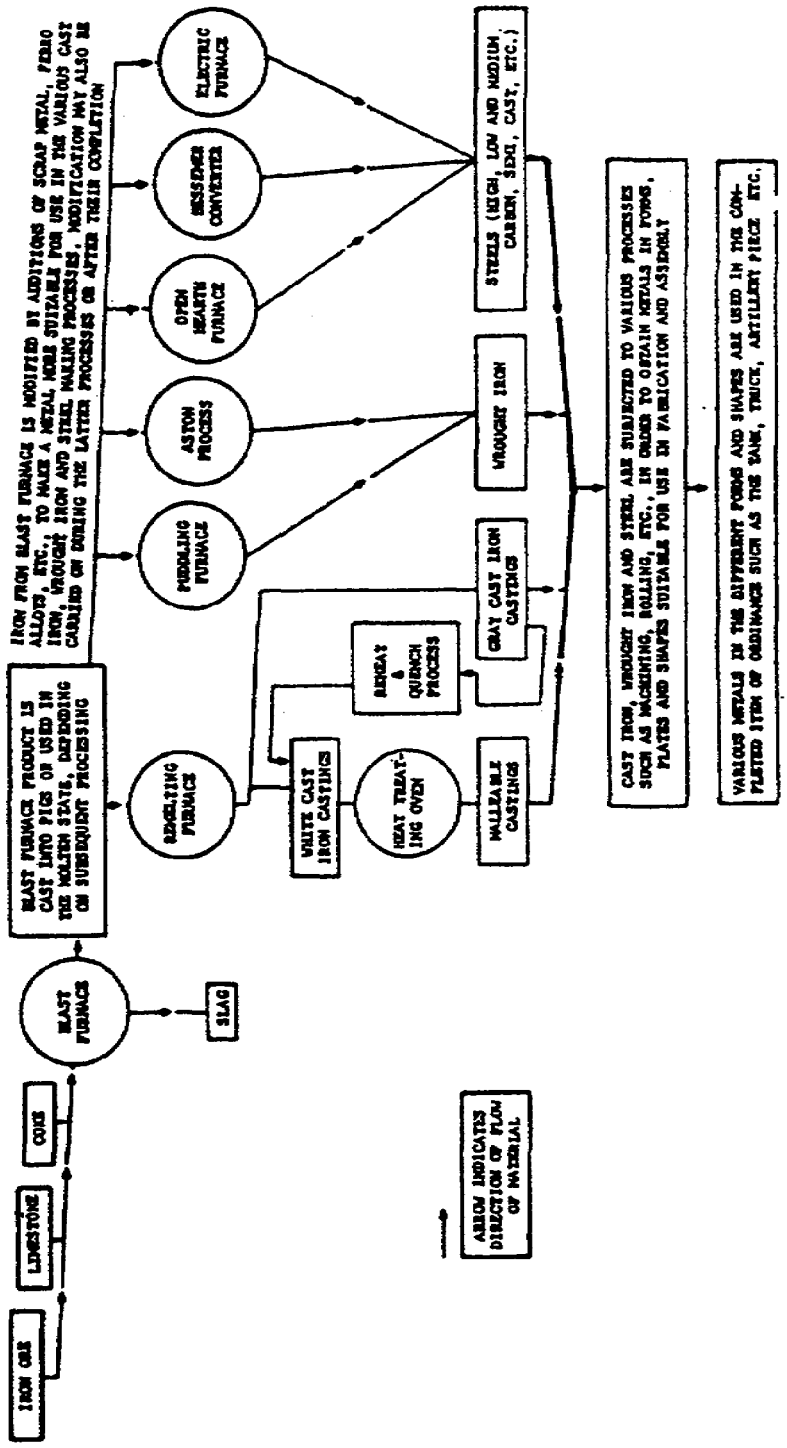
(b) *Capabilities*. Wrought iron can be gas or arc welded, machined, and hot- and cold-worked. It can also be plated.

(c) *Limitations*. Wrought iron has low hardness and low fatigue strength.

(2) *Cast Iron (Grey, White, and Malleable)*. Cast iron, developed in the latter part of the 18th century, is a man-made alloy of iron, carbon, and silicon. Cast iron is nothing more than basic carbon steel with more carbon added, together with silicon. A portion of carbon exists as free carbon or graphite. Total carbon content is between 1.7 and 4.5 percent.

(a) *Uses*. Cast iron is used to manufacture such items as water pipes, machine tool castings, transmission housings, engine blocks, pistons, and stove castings.

FIGURE 3. CONVERTING IRON ORE TO IRON.



(b) *Capabilities*. Cast iron is commonly brazed or bronze welded, but it can be gas or arc welded, hardened, or machined.

(c) *Limitations*. Cast iron must be preheated prior to welding; it cannot be cold-worked.

(d) *Grey Cast Iron*. If molten pig iron is permitted to cool quite slowly, the chemical compound of iron and carbon breaks up to a certain extent; much of the carbon separates out as tiny flakes of graphite scattered throughout the metal. This graphitic carbon, so-called to distinguish it from combined carbon, causes the gray appearance of a fracture which characterizes ordinary gray cast iron. Since graphite is an excellent lubricant, and since the metal is filled with tiny flaky cleavages, it is not difficult to understand why gray cast iron is so easy to machine, and why it cannot withstand a heavy shock. Gray cast iron consists of from 90 to 94 percent metallic iron with varying proportions of carbon, manganese, phosphorus, sulfur, and silicon. Special high-strength grades contain 0.75 to 1.5 percent nickel and 0.25 to 0.5 percent chromium, or 0.25 to 1.25 percent molybdenum. Commercial gray iron has 2.5 to 4.5 percent carbon. Of this quantity, about 1 percent of the carbon is combined with the iron, while about 2.75 percent remains in the free or graphitic state. In the production of gray cast iron, silicon content is usually increased, since this facilitates the formation of graphitic carbon. The combined carbon (iron carbide), which is a small percentage of the total carbon present in cast iron, is known as cementite. In general, the more free (graphitic) carbon present in cast iron, the lower the combined carbon content and the softer the iron.

(e) *White Cast Iron*. When gray cast iron is heated to the molten state, the carbon completely dissolves in the iron. If this molten metal is cooled quickly, the two elements remain in the combined state, and white cast iron is formed. The carbon in this type of iron is generally from 2.5 to 4.5 percent by weight and is referred to as combined carbon. White cast iron is very hard and brittle, often impossible to machine, and has a silvery white fracture surface.

(f) *Malleable Cast Iron*. Malleable cast iron is made by heating white cast iron to between

1,400° and 1,700° Fahrenheit for about 150 hours in boxes containing hematite ore or iron scale. This heating causes a portion of the combined carbon to change into the free or uncombined state. The free carbon separates out in a different manner from carbon in gray cast iron. It is called temper carbon, and it exists in the form of small, somewhat rounded particles, which give malleable iron castings the ability to bend before breaking and to withstand shock loads better than gray cast iron. The castings have properties like those of pure iron; namely, high strength, ductility, toughness, and ability to resist shock. Malleable cast iron can be brazed. Any welded part should be annealed after welding.

(3) *Steel*. Modern steel was first produced in the United States in 1860. Today, steels are produced in several different types of furnaces, as mentioned in paragraph 3b(4), page 9. The raw materials used to produce steel include pig iron, iron ore, limestone, and scrap metal. A form of iron, steel contains less carbon than cast iron but considerably more than wrought iron. Carbon content is from 0.03 to 1.7 percent. Basic carbon steels are alloyed with other elements, such as chromium and nickel, to increase certain physical properties of the metal.

(a) *Uses*. Steel is used to make such items as nails, rivets, gears, structural steel, axles, desks, vehicle body parts, and tools.

(b) *Capabilities*. Steel can be machined, welded, and forged to a varying degree depending on the type of steel.

(c) *Limitations*. Highly alloyed steels are difficult to fabricate.

(d) *Low-Carbon Steels*. These steels are soft and ductile and can be rolled, punched, sheared, and worked when either hot or cold. They are easily machined and can be readily welded by all methods. They do not harden to any appreciable amount when quenching from a high temperature.

(e) *Medium-Carbon Steels*. These steels may be heat-treated after fabrication and used for general machining and forging of parts that require surface hardness and strength. They are manufactured in bar form and in the cold-rolled or

the normalized and annealed condition. During welding, the weld zone will become hardened if cooled rapidly and must be stress-relieved after welding.

(f) *High-Carbon Steels*. These steels are used for the manufacture of drills, taps, dies, springs, and for those machine tools and handtools that are heat treated after fabrication to develop the hard structure necessary to withstand high shear stress and wear. High-carbon steels are manufactured in bar, sheet, and wire forms, and in the annealed or normalized and annealed condition, in order to be suitable for machining before heat treatment. These steels are difficult to weld because of the hardening effect of heat at the welded joint.

(g) *Tool Steels*. These steels are used in the manufacture of chisels, shear blades, cutters, large taps, wood-turning tools, blacksmith's tools, razors, and other similar parts where high hardness is required to maintain a sharp cutting edge. They are relatively difficult to weld due to the high carbon content.

(4) *Cast Steel*. Generally, welding is difficult on steel castings containing over 0.23 percent carbon and 0.2 percent silicon. Alloy steel castings containing nickel, molybdenum, or a combination of these metals, are readily welded if the carbon content is low. Those containing chromium or vanadium are more difficult to weld satisfactorily. Since manganese steel is nearly always used in the form of castings, and is difficult to weld, it is also mentioned in this paragraph. Its high resistance to abrasion is its most valuable property.

(5) *Steel Forgings*. Steel forgings may be made of carbon or alloy steels. Alloy steel forgings are harder and more brittle than low carbon steels. The surface of steel forgings is smooth. Where the surface of drop forgings has not been finished, there will be evidence of the fin that results from metal squeezed out between two forging dies. This fin is ordinarily removed by the trimming dies, but enough of the sheared surface remains for identification. All forgings are covered with reddish-brown or black scale, unless they have been purposely cleaned.

(6) *Alloy Steels*. Alloy steels are frequently recognized by their use. There are many varieties of alloy steels used in the manufacture of Army equipment. Each is best identified by experience. They have greater strength and durability then other carbon steels, and a given strength is secured with less material weight. Their economical use depends upon proper heat treatment to avoid weakening in the region of a weld. Nickel, chromium, vanadium, tungsten, molybdenum, and silicon are the most common elements used in alloy steels. A list of these types of steel is provided below:

(a) Chromium alloy.

(b) Nickel alloy.

(c) High chromium-nickel alloy (stainless steel).

(d) Manganese alloy.

(e) Molybdenum alloy.

(f) Titanium and columbium (niobium) alloy.

(g) Tungsten alloy.

(h) Vanadium alloy.

(i) Silicon alloy.

(j) High speed tool steel.

(k) High yield strength, low alloy structural steel.

d. *Nonferrous Metals*.

(1) *Aluminum*. The chemical symbol for this element is AL, and the principal ore of aluminum is bauxite which is produced by the weathering of aluminum silicate rocks. Aluminum is a lightweight, soft, low strength metal which can easily be cast, forged, machined, formed, and welded. It is suitable only in low temperature applications, except when alloyed with specific elements.

(a) *Uses*. Aluminum is used as a deoxidizer and alloying agent in the manufacture of steel. Castings, pistons, torque converter pump housings,

aircraft structures, railway cars, electrical transmission lines, and kitchen utensils are made of aluminum.

(b) *Capabilities*. Aluminum can be cast-forged, machined, and welded.

(c) *Limitations*. Direct metal contact of aluminum with copper and copper alloys should be avoided. Aluminum should also be used in low temperature applications.

(2) *Chromium*. The chemical symbol for chromium is Cr, and its ores are chromite and chrome ochre.

(a) *Uses*. Chromium is one of the most versatile and widely used alloys. It is used as an alloying agent in steel and cast iron and in nonferrous alloys of nickel, copper, aluminum, and cobalt. It is also widely used in electroplating for appearance and wear, in powder metallurgy, and to make x-ray targets, mirrors, and stainless steel.

(b) *Capabilities*. Chromium is hard, brittle, corrosion resistant, and can be welded, machined, and forged.

(c) *Limitations*. Chromium is not resistant to hydrochloric acid, nor can it be used in the pure state because of its brittleness and difficulty to work.

(3) *Cobalt*. The chemical symbol for cobalt is Co, and the chief ores of cobalt are cobaltite and smaltite.

(a) *Uses*. Cobalt is mainly used as an alloying element in permanent and soft magnetic materials, high-speed tools bits and cutters, high-temperature creep-resisting alloys, and cemented carbide tool bits and cutters. It is also used in making insoluble paint pigments and blue ceramic glazes.

(b) *Capabilities*. Cobalt can be welded, limitedly machined, and cold-drawn.

(c) *Limitations*. Cobalt must be machined with cemented carbide cutters.

(4) *Copper*. The chemical symbol for copper is Cu. Most copper produced today comes from

sulfurized ores, charlocite being the most important. Copper is a reddish metal, very ductile and malleable, and has high electrical and heat conductivity. It is used as a major element in hundreds of alloys. Chemically pure copper is not suitable for welding and, while very soft, it is difficult to machine due to its high ductility.

(a) *Uses*. The principal use of commercially pure copper is in the electrical industry where it is made into wire and other such conductors. It is also used in the manufacture of nonferrous alloys such as brass, bronze, and monel metal. Typical copper products are sheet roofing, ammunition cartridge cases, bushings, wire, bearings and ornamental statues.

(b) *Capabilities*. Copper can be forged, cast, and cold worked. It can also be welded, but its machinability is only fair.

(c) *Limitations*. Electrolytic tough pitch copper cannot be welded satisfactorily.

(5) *Lead*. The chemical symbol for lead is Pb; it is extracted from the material known as galena, the sulfide of lead. Lead is a heavy, soft, malleable metal, resistant to corrosion and particularly effective against many acids.

(a) *Uses*. Lead is used in the manufacture of electrical equipment, such as lead-sheathed power and telephone cables and storage batteries. Many types of chemical compounds, such as lead carbonate (paint pigment) and tetraethyl lead (antiknock gasoline) are produced from lead.

(b) *Capabilities*. Lead can be cast, cold worked, welded, and machined.

(c) *Limitations*. Lead has low strength with heavy weight, and lead dust and fumes are poisonous.

(6) *Magnesium*. The chemical symbol for magnesium is Mg. Its principal ores are dolomite, magnesite, and carnallite, but it occurs as magnesium chloride in certain natural salt brines and sea water.

(a) *Uses*. Magnesium is used as a deoxidizer for brass, bronze, nickel, and silver. It is used in commercial weight saving applications such as

aircraft parts, as a pyrotechnic for railroad signals and military purposes, and to make magnesium castings used for engine housings, blowers, hose pieces, and aircraft landing wheels.

(b) *Capabilities*. Magnesium can be forged, cast welded, and machined.

(c) *Limitations*. Magnesium in fine chip form will ignite at low temperatures (800 to 1,200° Fahrenheit). The flame can be smothered with suitable materials such as carbon dioxide (CO_2), foam, and/or sand.

(7) *Manganese*. The chemical symbol for manganese is Mn, and the chief ore of manganese is black manganese dioxide.

(a) *Uses*. Manganese is mainly used as an alloying agent in the manufacture of steel to increase its tensile strength. It is also added during the steel-making process to remove sulfur as a slag. Austenitic manganese steels are used for railroad trackwork, power shovel buckets, and rock crushers. Medium-carbon manganese steels are used in the manufacture of car axles and gears.

(b) *Capabilities*. Manganese can be welded, machined, and cold-worked.

(c) *Limitations*. Austenitic manganese steels are best machined with cemented carbide, cobalt, and high-speed cutters.

(8) *Molybdenum*. The chemical symbol for molybdenum is Mo, and its chief ores are molybdenite and wulfenite. Pure molybdenum has a high tensile strength and is very resistant to heat.

(a) *Uses*. Molybdenum is principally used as an alloying agent in steel to increase its strength, hardenability, and resistance to heat. Heating elements, switches, contacts, thermocouples, welding electrodes, and cathode-ray tubes are made of molybdenum.

(b) *Capabilities*. Molybdenum can be swaged, rolled, drawn, or machined.

(c) *Limitations*. Molybdenum can only be welded in an atomic hydrogen arc, or butt welded by resistance heating in vacuum. It is attacked by nitric acid, hot sulfuric acid, and hot hydrochloric acid.

(9) *Nickel*. The chemical symbol for nickel is Ni. It was first extracted from a copper-colored mineral named "kupfer nickel." Today it comes from sulfide, oxidized, and arsenical ores. Nickel is a grayish-white metal, very ductile, and malleable.

(a) *Uses*. Most nickel is used in the production of ferrous and nonferrous alloys. Chemical and food processing equipment, electrical resistance heating elements, ornamental trim, and parts subjected to elevated temperatures are all produced from nickel-containing metals. It is used as an alloy agent in the manufacture of stainless steel.

(b) *Capabilities*. Nickel alloys are readily welded by either the gas or arc methods. It can be machined, forged, cast, and easily formed.

(c) *Limitations*. Nickel cannot withstand heat above 600° Fahrenheit in a sulfidizing atmosphere. It oxidizes very slowly in the presence of moisture or corrosive gases.

(10) *Tin*. The chemical symbol for tin is Sn, and it is derived from the oxide cassiterite. It is a very soft, malleable, somewhat ductile, corrosion resistant metal, having low tensile strength and high crystalline structure.

(a) *Uses*. Its major application is in the coating of steel, and in the manufacture of containers for the preservation of perishable food. It is used in the form of foil for wrapping food products. It is also used as an alloying agent with copper to produce tin brasses and bronzes, with lead to produce solder, and with antimony and lead to form babbit.

(b) *Capabilities*. Tin can be cast, cold-worked, machined, and soldered.

(c) *Limitations*. Tin is not weldable.

(11) *Titanium*. The chemical symbol for titanium is Ti. It was discovered as the white metallic

oxide rutile. Today a relatively pure form of titanium metal is found throughout the world. It is a very soft, silvery white, medium-strength metal having very good corrosion resistance.

(a) *Uses*. Titanium is used as an alloy agent for aluminum, copper, magnesium steel, nickel, and other metals. It is also used in making powder for pyrotechnics and in manufacturing turbine blades, aircraft firewalls, engine nacelles, frame assemblies, ammunition tracks, and mortar base plates.

(b) *Capabilities*. Titanium can be machined at low and fast feeds, formed spot and seam-welded, and fusion-welded with inert gas.

(c) *Limitations*. Titanium has low impact strength, seizing tendencies, and low creep strength at elevated temperatures (above 800° F). It can be cast into simple shapes only.

(12) *Tungsten*. The chemical symbol for tungsten is W, and it is extracted in its pure state from wolframite and scheslite. It is hard, brittle, and nonmagnetic, and forms an oxide when heated in air.

(a) *Uses*. Tungsten is used in the manufacture of incandescent lamp filaments and phonograph needles; and as an alloying agent in the production of nonconsumable welding electrodes, armorplate, high-speed steel, and projectiles.

(b) *Capabilities*. Tungsten can be cold- and hot-drawn.

(c) *Limitations*. Tungsten is hard to machine, requires high temperatures for melting, and is usually produced by powdered metallurgy (sintering process).

(13) *Zinc*. The chemical symbol for zinc is Zn, and its principal ores are the sulfide blends, silicates such as willemite, and oxides such as franklite and zincite.

(a) *Uses*. The largest use of zinc is in galvanizing such items as pipe, tubing, sheet metal, and wire nails. It is also used as an alloying element in producing alloys such as brass, bronze, and in those alloys that are composed primarily of zinc itself.

(b) *Capabilities*. Zinc can be cast, cold-worked (extruded), machined, and welded.

(c) *Limitations*. The use of zinc die castings in continuous contact with steam is not recommended.

4. Conclusion

This task described the processes for identifying the physical and mechanical properties of various metals, and provided an explanation of the various categories of metals. It also served to provide the basis for the next task, which will describe the processes for identifying the physical and mechanical properties of various metals, and also describe the use of the hardness tester, chemical analysis, and bench grinder to identify various metals.

LESSON 1

THE PHYSICAL AND MECHANICAL
PROPERTIES OF VARIOUS METALS, AND USE OF
THE HARDNESS TESTER, CHEMICAL ANALYSIS, AND
BENCH GRINDER TO IDENTIFY VARIOUS METALS

TASK 2. Describe the processes for using the hardness tester, chemical analysis, and bench grinder to identify various metals.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within two hours

REFERENCES

No supplementary references are needed for this task.

1. Introduction

A very important part of the metalworker's skill lies in his ability to identify various metal products brought to the shop. He must be able to identify the metal so that he can apply the proper work methods of welding or machining to restore broken parts and put them back into service, or to fabricate new parts to replace those that are beyond repair. But whether the work method to be applied is to be welding or machining, the metalworker must be familiar with the various metals and should also be acquainted with the methods used for identification of metals. Drawings of Army materiel are usually available and may be used to identify the type of metal used in the various parts. However, if they are not available, simple tests can be conducted in the shop to identify metals. Since the quality of test depends upon close observation and experience, their procedures should be practiced diligently

until they are learned. These tests are described in the following paragraphs.

2. Tests Used to Identify Metals

a. *General*. Simple tests can be conducted in the shop to identify the different metals. Since the ability to judge can be developed only through personal experience, practice these tests with known metals until you are familiar with the reactions of each metal to each type of test. The tests are described in the following subparagraphs.

b. *Appearance/Chemical Analysis*. Appearance/chemical analysis, as the name implies, is based on the general appearance of the metal, which includes such general features as the color and texture of machined and unmachined surfaces. It is obvious that the appearance portion of this type test is not an extremely accurate method; however, the experienced metalworker can make a reasonably good determination based on experience and the above mentioned characteristics. The chemical analysis procedure referred to in the following paragraphs is confined to the analysis used to distinguish between aluminum and magnesium, and between steel and aluminum or lead.

c. *Fracture*. The fracture of many metals may be used for identification through the appearance of the fracture and study of metal chips. This test is made by simply notching a specimen and then breaking it. Although no measurable indications of the properties of a metal are obtained from this test, many metals can, through experience, be quickly identified by examining the surface of the break, or by studying the chips produced with a hammer and chisel. The fracture test is probably the oldest of the methods used in the inspection and testing of metals.

d. *Sparks*. When the exact type of material is unknown, a spark test may be used to determine its identity. The test is conducted by a study of the sparks formed when the material is held against a high-speed grinding wheel. A grinding wheel may be used on the various types of iron and steel because they produce sparks which vary in length, shape, and color when held lightly against a grinding wheel. When any form of iron or steel is held against a grinding wheel, small particles, heated to a red or yellow heat, are released from the metal

and thrown into the air. Through contact with the oxygen in the air, the particles oxidize, or burn. If an element such as carbon is present in various quantities rapid burning occurs, resulting in the bursting of the carbon particles. Because of their varied carbon content, the various forms of iron and steel produce sparks that vary in length, shape, and color. The grinding wheel should be of the aluminum oxide type, hard enough to wear reasonably long, yet soft enough to retain free cutting properties. The peripheral speed should be approximately 4000 feet per minute in order to produce good, short bright sparks. The tests should be conducted in diffused daylight against an ordinary background. In all cases, it is advisable to grind standard samples of metals of known composition so that the sparks produced can be compared with those emitted by the material under test.

e. *Torch*. The behavior of metal under a torch can be identified with different metals by studying the melting rate, the appearance of the molten metal, and slag and color changes during heating. In other words, with the oxyacetylene torch, one can identify a metal by studying how fast it melts and by the color changes during heating.

3. Appearance and Chemical Analysis of Various Metals

a. *General*. The following subparagraphs provide a list of the general appearance of various ferrous and nonferrous metals. The chemical analysis portion is discussed only where applicable.

b. *Appearance of Ferrous Metals*.

(1) *Gray Cast Iron*. When visually observing gray cast iron, the unmachined surfaces are very dull gray in color and somewhat roughened by the sand mold used in casting the part. Unmachined castings may have brighter areas where rough edges have been removed by grinding.

(2) *Malleable Cast Iron*. The surface of malleable iron is much like gray cast iron; however, the dull gray color is somewhat lighter and the surface is usually free from sand.

(3) *Wrought Iron*. The appearance of wrought iron is the same as that of rolled low-carbon steel discussed in paragraph 3b(4)(b), below.

(4) *Low-Carbon Steel*. The appearance of low-carbon steel depends upon its method of preparation rather than on its composition.

(a) *Cast Steel*. Cast steel has a relatively rough, dark surface, except where machined.

(b) *Rolled Steel*. Rolled steel has fine surface lines running in one direction.

(c) *Forged Steel*. Forged steel is usually recognizable by its shape, hammer marks or fins.

(5) *High-carbon Steel*. High-carbon steel may be identified by its unfinished surface, which is dark gray. These steels can be worked to a smoother finish than the less costly low-carbon steels.

(6) *Cast Steel*. The surface of cast steel is brighter than cast or malleable iron and sometimes contains small bubblelike depressions.

(7) *Steel Forgings*. Steel forgings have a smooth surface. If the forgings have not been finished fins, caused by metal squeezing out between the forging dies, will be evident. If it is a finished forging, the area from which the fins have been removed will be noticeable. Unless these forgings have been properly cleaned, they will be covered with a reddish-brown or black scale.

(8) *Distinguishing Between Steel and Aluminum or Lead*. Steel is distinguished from aluminum or lead by the application of a copper sulfate solution. This solution is spread on the surface of the metal with a small brush or with the end of a clean cotton rag. The copper sulfate does not react with aluminum or lead, but it leaves a copper coating on the surface of steel.

c. *Appearance of Nonferrous Metals*.

(1) *Aluminum*. Aluminum is identified by its light gray to silver color and light weight. When polished it is very bright, becoming dull when it is oxidized. Rolled and sheet aluminum materials are usually pure metal. Castings are alloy of aluminum with other metal, usually zinc, copper,

silicon and sometimes iron and magnesium. Wrought aluminum alloys may contain chromium, silicon, magnesium, or manganese. Aluminum, which resembles magnesium, can be distinguished by the application of a drop of silver nitrate solution on each surface. The silver nitrate will not react with aluminum, but leaves a black deposit of silver on magnesium. A copper sulfate solution is used as discussed in paragraph 3b(8), page 27, to distinguish steel from aluminum or lead.

(2) *Aluminum Bronze*. The aluminum bronze metals are yellow in color but, when polished, they are darker than brass.

(3) *Polished Brasses and Bronzes*. The colors of polished brasses and bronzes will vary from an almost copper-color red to yellow, depending on the composition of the metal. These metals will oxidize to various shades of green, brown, and yellow.

(4) *Copper*. Copper is a lustrous, reddish-brown metal. When polished it gives a red appearance and it will oxidize to various shades of green.

(5) *Lead*. Lead is white in color when freshly cut and becomes dull gray when exposed to the air. A copper sulfate solution is used to distinguish steel from lead, as discussed in paragraph 3b(8), page 27.

(6) *Magnesium*. Magnesium is silver-white when polished, but oxidizes rapidly to a grayish film. It weighs about one-third less than aluminum, which it otherwise resembles. To distinguish aluminum from magnesium, a silver nitrate solution is used, as discussed in paragraph 3c(1), beginning on page 27.

(7) *Monel*. Monel metal is an alloy of nickel, copper, iron, and manganese. It is light gray in color and dulls to a darker gray on aging.

(8) *White Metal*. White metal castings are usually made with alloys of aluminum, lead, magnesium, and tin. With the exceptions of those made with lead or tin, they are lightweight and notably white in color. The surface is much smoother than that of castings produced by the use of sand.

4. Fracture

Many metals can be identified by the appearance of the surface of the broken part or by studying the chips produced with a hammer and chisel, as described in the following paragraphs.

a. *Gray Cast Iron*. Nick a corner of the gray cast iron with a chisel or hacksaw and break off by a sharp blow with a hammer. The break will be short and the exposed surface will be dark gray in color. This color is caused by the fine specks of carbon present in the form of graphite dispersed throughout the metal. Chips raised by a chisel break off as soon as formed.

b. *Malleable Iron*. The central portion of the broken surface is dark gray with a bright steel-like band around the edge, somewhat like a picture frame. When of good quality, malleable iron is much tougher than cast iron and does not break short when nicked.

c. *Wrought Iron*. Wrought iron can be bent and is quite ductile. When nicked and bent to the breaking point, the break is jagged. Wrought iron has a fibrous structure and can be split in the direction in which the fibers run. It is easily cut with a chisel.

d. *Low-Carbon Steels*. When low-carbon steel are fractured, the color is bright crystalline gray. The metal is tough when chipped or nicked.

e. *High-Carbon Steels*. These steels are harder and more brittle than low-carbon steel and the fracture is whiter and finer grained.

f. *Steel Forgings*. Forgings may be of low-carbon, high-carbon, or tool steel and the color will vary from bright crystalline to silky gray. When the specimen is nicked, it is harder to break than cast steel and has a finer grain.

g. *Alloy Steels*. Generally, the alloy steels are very fine grained. Sometimes the fracture has a velvety appearance.

h. *Steel Castings*. The surface of the fractured area is bright crystalline gray. Steel castings are tough and do not break short. Chips made with

a chisel curl up, except manganese steel which can not be cut with a chisel.

i. *Aluminum*. Aluminum castings show a bright crystalline structure. A fracture in rolled aluminum sections shows a smooth and bright surface.

j. *Aluminum Bronze*. The fractured surface of aluminum bronze is smooth.

k. *Brasses and Bronzes*. The fractured surface ranges from smooth to crystalline, depending on the composition of the metal and on whether it has been cast, forged, or rolled.

l. *Copper*. Copper presents a smooth surface with no crystalline appearance.

m. *Lead*. Lead has a smooth gray-white surface when polished, oxidizing to a dull gray.

n. *Magnesium*. The fractured surface is rough and finely granular.

o. *Monel Metal*. The fractured surface is crystalline. Its color is similar to that of nickel.

p. *White Metal Die Castings*. The fracture is white and somewhat granular.

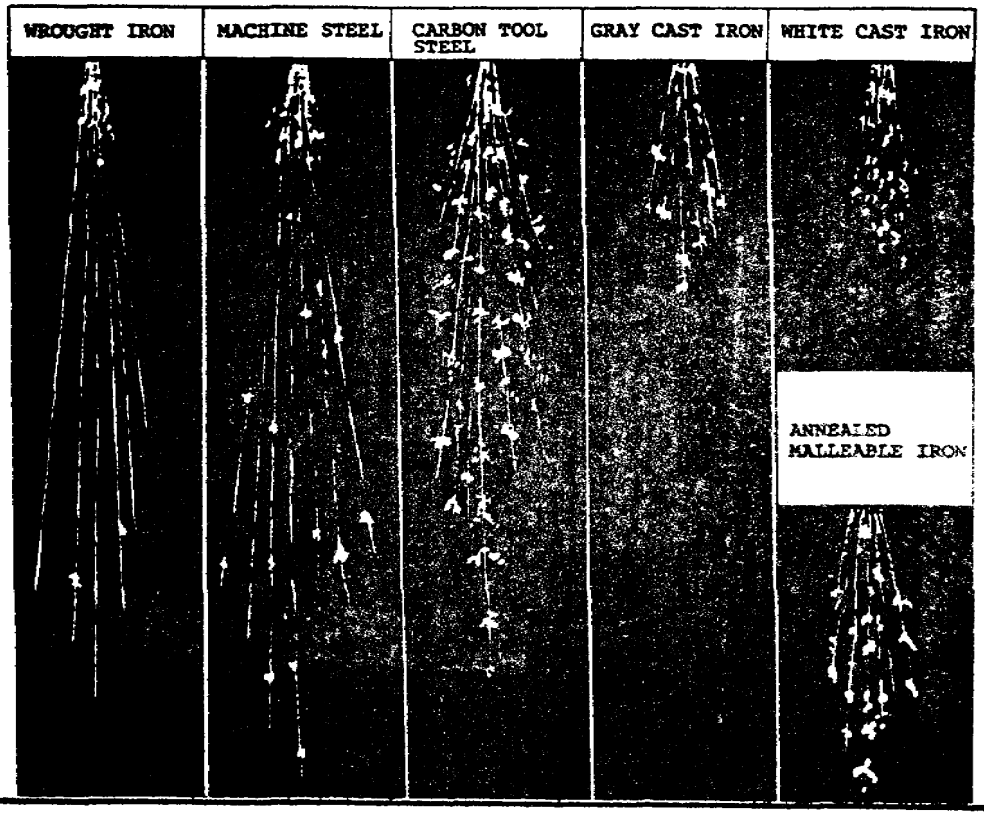
5. Spark Test

a. *General*. When the exact type of metal is not known, a spark test may be used to determine its identity. This identity is revealed by a study of the sparks formed in the stream emitted into the air when the material is held against a high-speed grinding wheel (bench, pedestal, or portable hand grinder). Examples of the spark streams formed by different metals are provided in figures 4 and 5 on the following pages. Spark testing is a rapid economical method of separating and classifying types of irons and steels and some nonferrous metals.

b. *Degree of Spark Stream Glow*. The degree of glow observed in the formation of sparks in the spark stream is a function of the grinding resistance and other conditions which affect the initial temperature of the metal chip and the

oxidation of elements present in the specimen. For example, gray cast iron is much lower in resistance than a ductile steel and its initial sparks are proportionately lower in color temperature. The presence of carbon in the iron causes high intensity spurts as the carbon burns in the air a short distance from the grinding wheel. Carbon is a necessary element for spurts or bursts. Some soft nonferrous metals, such as copper, brass, and aluminum, yield no true grinding sparks in the air. The first temperature glow color is produced by heat generated when a chip is torn from the metal specimen. As the chip of iron or steel speeds through the air, higher temperatures and more brilliant color are reached through oxidation. Spear points at the end of the visible lines are observed from several steels, but are especially noticeable when the steel contains molybdenum. Figures 4 and 5 below and on the following page, also serve to illustrate the variations in the direction of fire sparks near the grinding wheel.

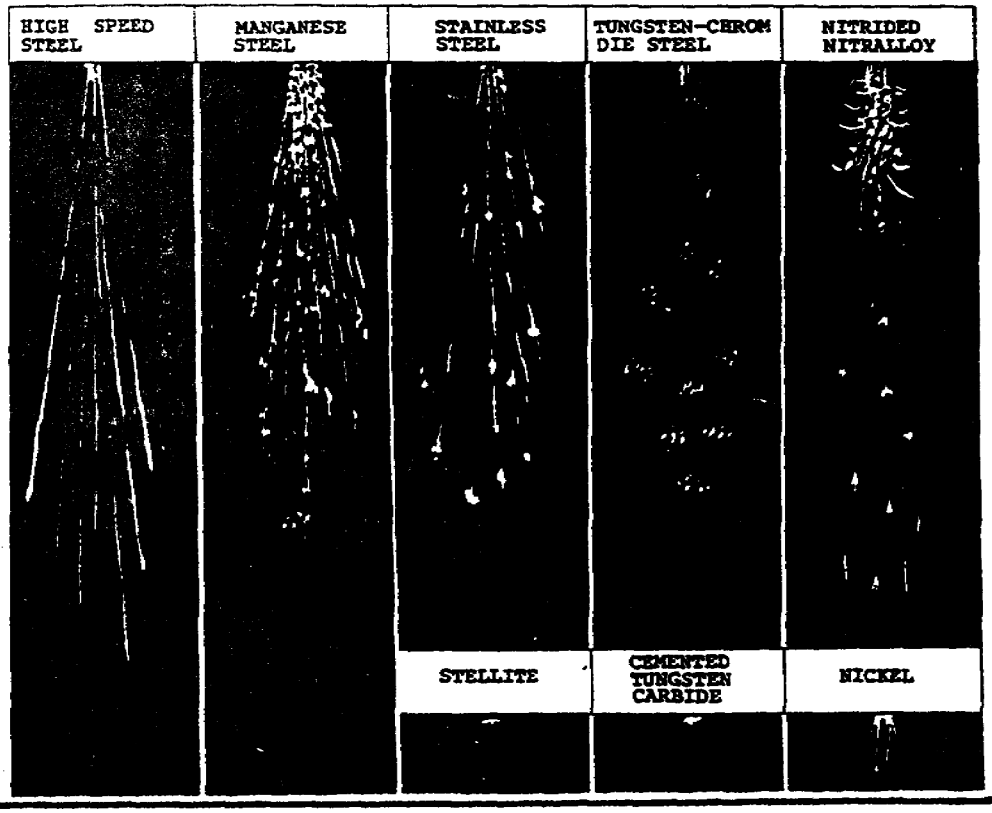
FIGURE 4. SPARK TEST CHARACTERISTICS OF METALS.



c. *Technique of Comparison*. Table 1, on the following page, together with the sketches provided in figures 4 and 5 are employed to indicate the important differences among sparks from a wide variety of metals. The terms used in the table are relative rather than absolute. The length of the spark stream depends on the pressure between the wheel and work. Apparent color depends upon the light in which the inspection is made. The difference between red and orange, as tabulated in Table 1, is very slight. The colors straw and white, listed in the table, might be called yellow, depending on the extraneous light. Figures 4 and 5, cannot convey a true picture of sparks as seen by the human eye. But, these figures will help to classify and illustrate pronounced differences.

d. *Operation of Equipment*. When making a grinding test, neither the grinding wheel nor the machine on which it is mounted need be selected to

FIGURE 5. SPARK TEST CHARACTERISTICS OF METALS (CONTINUED).



specifications. The wheel should not be dulled or in a loaded condition. Use only hand pressure, holding the metal specimen lightly and constantly against the grinding wheel so that the spark stream may be seen, so that the area and length of the

TABLE 1. SPARK TEST CHARACTERISTICS OF METALS (CONTINUED).

Metal	Volume of Stream	Relative Length of Stream, Inches	Color of Stream Close to Wheel	Color of Streaks Near End of Stream	Quantity of Sparks	Nature of Sparks
Wrought iron	Large	65	Straw	White	Very few	Forked
Machine steel	Large	70	White	White	Few	Forked
Carbon tool steel	Moderately large	55	White	White	Very many	Fine, repeating
Gray cast iron	Small	25	Red	Straw	Many	Fine, repeating
White cast iron	Very small	20	Red	Straw	Few	Fine, repeating
Annealed malL. iron	Moderate	30	Red	Straw	Many	Fine, repeating
High-speed steel	Small	60	Red	Straw	Extremely few	Forked
Manganese steel	Moderately large	45	White	White	Many	Fine, repeating
Stainless steel	Moderate	50	Straw	White	Moderate	Forked
Tungsten-chromium die steel	Small	[illegible]	Red	Straw	Many	Fine, repeating
Nitrided nitralloy	Large (curved)	55	White	White	Moderate	Forked
Stellite	Very small	10	Orange	Orange	None	. . . .
Cemented tungsten carbide	Extremely small	8	Light orange	Light orange	None	. . . .
Nickel	Very small	15	Orange	Orange	None	. . . .
Copper, brass, aluminum	None	. .	. . . .	. . . .	None	. . . .

stream are a function of the metal specimen rather than of grinding conditions. Use a portable grinder to spark test heavy pieces of metal. Make sure that the full length of the spark stream can be seen to permit adequate inspection.

e. *Specific Metals*. Refer to figures 4 and 5 (on pages 31 and 32) during the discussion of the specific metals in the following paragraphs.

(1) *Wrought Iron*. Wrought iron represents nearly pure iron with very few spurts.

(2) *Low-carbon Machine Steel*. Low-carbon machine steel yields a few plain forked spurts. As the carbon content is increased in plain steel, the explosions increase and assume more intricate patterns.

(3) *Carbon Tool Steel*. In carbon tool steel the initial explosions called "bursts", produced by its carbon content, are so profuse that the stream becomes very bushy. Particles from the initial bursts dart out and produce secondary explosions called "spurts" which in turn produce a fine branching network of light.

(4) *Gray, White, and Malleable Cast Irons*. The difference among these three cast irons is not apparent at first glance. Streaks near the wheel are red and spurts from all three are similar to those from carbon tool steel. However, the length of the stream from each will vary. Gray cast iron produces a small volume of dull, red sparks that form a straight line close to the grinding wheel. These sparks break up into many fine repeated spurts which change to a straw color. White cast iron shows many fine noncurving streaks close to the wheel. When malleable cast iron is ground, the outer bright layer gives off bright sparks like steel. As the interior of the malleable cast iron is reached, the sparks quickly change to a dull red color near the wheel. These sparks from the interior section are very much like those of gray cast iron; however, they are somewhat longer and are present in a larger volume.

(5) *High-speed Steel*. High-speed steel is not easily mistaken when inspected by the spark method. The dull color near the wheel and its long spark stream are very apparent.

(6) *Manganese Steel*. Manganese steel yields a brilliant stream of very high temperature. The brilliance is due to the fine chip size and easy oxidation.

(7) *Stainless Steel*. Stainless steel could be confused with machine steel; however, stainless steel sparks are of less brilliant color near the wheel and the stream itself is thinner.

(8) *Plain Carbon Steel and Stainless Steel*. These are two types of metal whose sparks vary widely, depending upon composition. Spurts from structural and machine steels cover a large part of the range between wrought iron and carbon tool steel, being influenced by their carbon content. Different brands of stainless steels and irons yield spark streams with a wide divergence of volume and color. The spark stream shown is from steel that is from a 12 to 14 percent chromium, low-carbon type.

(9) *Tungsten-chromium Die Steel*. Like cast iron, the sparks emitted by tungsten-chromium die steel are red near the wheel, turning to a straw color at the end of the stream. But tungsten-chromium die steel is noticeably different than the cast irons, as indicated by blue-white glows at the spurts.

(10) *Nitrided Nitralloy*. This metal exhibits one peculiar characteristic; the sparks near the wheel form whorls and some actually turn from the main line of travel by as much as 90°. The same tendency, to a lesser extent, is exhibited by manganese steel.

(11) *Stellite and Cemented Carbide*. Stellite and cemented carbide, in contrast to their brilliant performance as tools, provide very little spark action. As seen in figure 5 on page 32, the spark of these two metals is hardly noticeable. Any oxidation that occurs in the air does not raise the spark temperature appreciably. The line of travel is plain and short. Temperature color from the carbide material is slightly higher that from the stellite and the stream is very short. These differences are attributed to grinding sparks from the more resistant cemented carbide.

(12) *Nickel*. Nickel yields a spark that at first may be confused with a stellite spark.

However, closer observation will reveal a wavy motion of some of the nickel streaks while the stellite streaks are all straight. Streaks from these last three metals taper into extinction.

f. *Identification of Sparks*. An important aspect in spark testing is a good set of specimens of known composition. These can serve as a standard for learning to identify the various types of sparks and for comparison with metals of unknown composition. When a spark stream is studied carefully, it becomes apparent that it consists of a large number of sparks of various lengths which look alike except for size. A spark is understood to mean not only the main shaft or carrier line, but also any burst and other details which may develop from it. The details of a spark stream can often be seen better by reducing the grinding pressure so there are fewer overlapping sparks. The effects of alloying elements in the spark stream are important because of their influence on the stream. These effects are discussed in the following subparagraphs.

(1) *Wrought Iron with Carbon*. The spark stream of an alloy containing about 0.08 percent carbon consists of long, moderately bright carrier lines each of which thickens strongly at the end and is followed by a fairly dull arrowhead separated by a small gap from the rest of the spark. The sparks range in length all the way from 1 or 2 inches up to roughly 25 inches.

(2) *Manganese*. Manganese affects the spark stream in much the same way as carbon and steel containing 1 or 2 percent of manganese may be confused with carbon steel. When the manganese content rises to 10 or 12 percent, the spark stream retains its brilliance and the length of the stream drops to about 20 inches, as compared with 30 inches for carbon steels.

(3) *Nickel*. The distinguishing feature of the spark is a short sharply outlined dash appearing near the end of the carrier just before the fork.

(4) *Chromium*. In steels that contain 1 or 2 percent chromium there will be nothing to indicate its presence. But, an 18 percent chromium content produces a spark much like wrought iron, except that it is only half as long.

(5) *Molybdenum*. Small amounts of molybdenum in steel can be recognized by the detached arrowhead in a stream that otherwise looks much like that of wrought iron.

(6) *Tungsten*. This is the easiest metal of all to recognize because of the dull red color it imparts to the spark stream, especially near the grinding wheel.

(7) *Cast Iron*. Cast iron sparks are of medium length; the carrier lines are dull red near the grinding wheel and they end in bright curved spear points coming out of very fine carbon bursts.

(8) *High-Speed Steel with Tungsten*. The spark streams are very simple in appearance and are composed of a few long, dull-red, carrier lines having no carbon bursts at all.

(9) *High-Speed Steel with Molybdenum*. For this type steel, the spark stream is shorter and denser than for high-speed steel with tungsten. The sparks are definitely orange or straw in color with small amounts of red near the grinding wheel. The carrier lines end in spear points preceded by at least occasional carbon bursts.

g. *Factors Affecting the Spark Stream*. The streams emitted by high-speed steels are affected considerably by a number of factors. The following subparagraphs provide a listing of these factors.

(1) Grinding conditions and the condition of the steel itself.

(2) Whether the steel is annealed or hardened.

(3) Whether a small wheel on a portable grinder, as opposed to a large wheel on a bench grinder, is used.

(4) Grinding pressure, specimen size, and the shape of the region being ground.

(5) The best way to avoid pitfalls is to perform the spark test by direct comparison with a standard of known composition. Only in this manner can the maximum benefits of spark testing be obtained.

6. Torch Test

a. *General*. Various metals can be identified by using an oxyacetylene torch and observing how fast the metal melts, the appearance of the puddle of molten metal and slag, and by the color changes that occur during heating of the metal. The following paragraphs serve to describe the effects of the torch test on various metals.

b. *Gray Cast Iron*. A heavy tough film forms on the surface as it melts. The puddle is quiet and very fluid. When the torch flame is raised, the depression in the surface of the puddle disappears instantly. The molten puddle solidifies slowly and gives off no sparks.

c. *Malleable Iron*. The molten metal boils under the torch flame and, when the flame is withdrawn, the surface will be full of blow-holes. The melted part will cool very hard and brittle; it is, in fact, white cast iron or chilled iron produced by the melting and comparatively rapid cooling. The outer steel-like shell will give off sparks under the torch, while the center portion will not.

d. *Low-carbon Steels*. The steel gives off sparks when melted and, when the flame is removed, solidifies almost instantly.

e. *High-carbon Steels*. The molten metal is brighter than molten low-carbon steel and the melted surface has a cellular appearance.

f. *Steel Forgings*. Steel forgings spark when melted. The greater the carbon content, the greater the number and brilliance of the sparks.

g. *Alloy Steels*. Steels containing a considerable quantity of chromium display a greenish-colored slag on the weld or puddle when cold. In general, the effects of the torch test depend on the composition of the alloy steel and must be determined by trial and experience.

h. *Cast Steels*. The steel sparks when melted and solidifies quickly.

i. *Aluminum*. Aluminum does not show red before melting. It holds its shape until almost molten and then collapses suddenly. A heavy coating of white oxide forms instantly on the molten surface.

j. *Aluminum Bronzes*. The surface is quickly covered with a heavy scum that tends to mix with the molten metal and is difficult to remove. Welding of these bronzes is extremely difficult.

k. *Brasses and Bronzes*. True brass contains zinc which gives off white fumes when melted, while bronzes contain tin that increases fluidity. Some bronzes contain zinc and will fume, but not as much as brass.

l. *Copper*. Because of the heat-conducting properties of copper, a larger flame is required to produce fusion than for other metals. Copper melts suddenly and solidifies instantly. Copper alloys, containing small amounts of other metals, melt quicker and solidify slower.

m. *Lead*. Lead melts at a very low temperature and the molten metal becomes covered with a thin, dull slag.

n. *Magnesium*. Magnesium oxidizes rapidly when heated in the air to its melting point; because of this and as a safety precaution, this metal is melted in an atmosphere free from oxygen. When heated in the open air, it produces an oxide film which is highly refractory and insoluble in the liquid metal.

o. *Monel Metal*. Monel flows clearly without any sparkle. A heavy black scale forms on cooling.

p. *White Metal Die Castings*. The melting points are low and the metal will boil under the torch.

7. Hardness Testing

a. *General*. The quality of hardness is a complex one which detailed study has shown to be a combination of a number of physical properties. It is most often defined in terms of the method used for its measurement and usually means the resistance of a substance to indentation. Hardness may also be defined in terms of resistance to scratching and, thus, is related to wear resistance. The word "hardness" is sometimes used to refer to the stiffness or temper of wrought products because the indentation hardness of a metal is closely related to its tensile strength. The cutting characteristic of metal, when used as a tool, is sometimes called its hardness, but

reflection will show that these various indications of hardness are not the same. The following subparagraphs describe the processes for the performance of various hardness tests.

b. *Brinell Hardness Test*. One of the most common methods of measuring the hardness of a metal is to determine its resistance to the penetration of a nondeformable steel ball. This is done by determining the depth to which such a ball will sink into metal under a given load. This test is made by forcing the hardened steel ball into the test material by the weight of a known load. The ball is usually 10 millimeters in diameter and has an applied pressure of 500 kilograms for soft materials such as copper and brass, and 3000 kilograms for materials such as iron and steel. Once the load has been applied, the diameter of the resulting impression is measured with a small microscope. The hardness number of the metal is found by dividing the load applied by the area of the impression and comparing the results of the division with a standard hardness conversion table, which provides the hardness number of the metal.

c. *Rockwell Tester*. This test is based upon the difference between the depth to which a test point is driven into a metal by a light load and the depth to which it is driven by a heavy load. The light load is applied first and then, without moving the piece being tested, the heavy load is applied. The hardness number is automatically indicated on a dial. In this test, a 120° diamond cone for hard metals or a 1/16 inch steel ball for softer materials is impressed into the surface to be tested by a deadweight acting through a series of levers. The hardness is indicated on a dial gage graduated in the Rockwell "B" and "C" scales. The harder the piece, the higher the Rockwell number will be. For example, machinable steel should not show a reading of more than 30 to 35 on the Rockwell "C" scale, while a hardened high-speed cutter would show a reading of 63 to 65. When testing hard steel, the diamond point should be used and should be read on the "C" scale. For nonferrous metals, the steel ball should be used and read on the “B” scale.

d. *Vickers Hardness Test*. The Vickers hardness testing method is very similar to the Brinell method. The penetrator used in the Vickers machine is a diamond pyramid rather than the round steel

ball of the Brinell. The impression made by this penetrator is a dark square on a light background. This type of impression is easier to measure than the circular impression. Another advantage lies in the fact that the diamond point does not deform as is possible with the steel ball.

e. *Scleroscope Test*. With this process, the hardness is measured by the height of rebound of a diamond-pointed hammer after it has been dropped through a guiding glass tube onto the test piece and the rebound checked on a scale. The harder the material used, the greater the rebound of the hammer because the rebound is directly proportional to the resilience or springiness of the test piece. The height of the rebound is recorded on a gage. Since the scleroscope is portable, it can be carried to the work enabling tests to be performed on a large section of metal too heavy to be carried to the work bench. The indentations made by this test are very slight.

f. *File Test*. The file test is a method of determining the hardness of a piece of material by trying to cut into it with the corner edge of a file. The hardness is indicated by the bite that the file will take. This is the oldest and one of the simplest methods of checking hardness; it will give results ranging from quite soft to glass hardness. The principal objection to the use of the file test is that no accurate record of results can be maintained as numerical data.

8. Other Systems for Identification of Metals

a. *Numerical Index System*. One of the most widely known and generally used numbering systems for steel specifications and compositions is the one established by the Society of Automotive Engineers (SAE), known as SAE designations. The specifications were originally intended for use in the automotive industry; however, their use has spread into all industries where steel and its alloys are used. As the title implies, this is a numerical system used to identify the compositions of the SAE steels. With only a few exceptions, plain steels and steel alloys are identified by a four-digit numbering system. By using this procedure, it is possible to use numerals on shop drawings and blueprints to partially describe the composition of the material referred to. To provide a better understanding of the SAE system,

assume that a shop drawing indicates the use of 2340 steel. The first digit represents the major alloying element or type of steel to which it belongs; in this case, a nickel alloy. In the simple alloy steels, the second digit generally indicates the approximate percentage of the predominant alloying element (3 percent nickel). The last two digits always indicate the carbon content in points, or hundredths of 1 percent (i.e., 0.40 hundredths of 1 percent carbon). From this explanation, it can be seen that a 2340 designation indicates a nickel steel of approximately 3 percent nickel and 0.40 hundredths of percent carbon. The basic numerals for the various types of SAE steel are as follows:

Type of Steel	***Numerals/Digits***
Carbon steel	1XXX
Plain carbon	10XX
Free cutting (screw stock)	11XX
Manganese steels	13XX
Nickel steels	2XXX
3.50 % nickel	23XX
5.00 % nickel	25XX
Nickel-chromium steels	3XXX
1.25% nickel, 0.60% chromium	31XX
1.75% nickel, 1.00% chromium	32XX
3.50% nickel, 1.50% chromium	33XX
Corrosion- and heat-resisting	30XX
Molybdenum steels	4XXX
Carbon - molybdenum	40XX
Chromium - molybdenum	41XX
Chromium - nickel - molybdenum	43XX
Nickel - molybdenum	46XX & 48XX
Chromium steels	5XXX
Low chromium	51XX
Medium chromium	52XX
Corrosion- and heat-resisting	51XX
Chromium - vanadium steels	6XXX
1% chromium	61XX
Silicon - manganese steels	9XXX
2% silicon	92XX

b. *Color Code*. The Bureau of Standards, United States Department of Commerce, has prepared a color code for marking steel bars. The work of preparing this color code was undertaken initially at the request of the National Association of Purchasing Agents. The color markings provided in the code may be applied by painting the ends of the steel

bars. Solid colors usually designate carbon steel, while twin colors designate alloy and free-cutting steel.

9. Conclusion

This task described the processes for using the hardness tester, chemical analysis, and bench grinder to identify various metals. In addition, the task described the numerical index system, the color code and the four types of tests that can be performed in the shop for identifying different metals. The next requirement is a practical exercise consisting of several questions designed to reinforce the objectives covered in the two tasks of this lesson.

PRACTICAL EXERCISE 1

1. Instructions

Read the scenario and respond to the requirements that follow the scenario.

2. Scenario

You are assigned to an intermediate general support (IGS) maintenance company stationed in, West Germany. The shop officer in this organization has established a cross-training program for the company where each repair section of the company maintenance shops conducts training in its pertinent technical area (of the IGS maintenance mission), to personnel from the other shop sections. This program was established to provide personnel with a better appreciation for the work conducted in the various sections of the shops, and to permit better utilization of personnel among work sections experiencing a shortage of personnel or a work overload.

You are the repair shop technician in charge of the service section consisting of the machine, welding, metal body, radiator, canvas, and glass repair shops. In consonance with the established cross-training program, you developed a training plan for identifying the physical and mechanical properties of various metals, and for the use of the hardness tester, chemical analysis, and the bench grinder to identify various metals. You also developed a group of questions which will be administered upon completion of your block of instruction to ensure the accomplishment of the training objectives.

3. Requirement

Your task is to provide the correct answer to the questions which you developed and which appear below. You may use the text in tasks 1 and 2 of this lesson to assist you in developing the correct answers.

a. List two of the physical properties of metals.

b. List three of the mechanical properties of metals.

c. What is the purpose of using the element of carbon in plain carbon steel?

d. On what does the classification of metal as a cast iron or as one of the steels depend?

e. List two ferrous metals.

f. List two nonferrous metals.

g. List the four tests that can be conducted in the shop for identifying metals.

h. In what type metal are the unmachined surfaces very dull gray in color and somewhat roughened by the sand mold used to cast the part?

i. What type metal will sometimes contain small bubblelike depressions on its surface?

j. What is the name of the test that is conducted with the use of a grinding wheel for identifying the exact type of a metal?

k. What is the type of metal where the bursts produced by its carbon content are so profuse that the stream emitted by grinding becomes very bushy and particles from the initial bursts produce secondary bursts resulting in a fine branching network of light?

l. What chemical solution is used to distinguish steel from aluminum or lead?

m. What chemical solution is used to distinguish aluminum from mangnesium?

n. What type of hardness test uses the rebound of a diamond-pointed hammer to determine the hardness of a metal?

LESSON 1. PRACTICAL EXERCISE - ANSWERS

1. Requirement

a. (1) Co-efficient of linear expansion
(2) Heat and electrical conductivity
(3) Magnetic susceptibility
(4) Reflectivity
(5) Specific gravity
(6) Melting point

b. (1) Strength
(2) Elasticity
(3) Modulus of elasticity
(4) Ductility
(5) Malleability
(6) Toughness
(7) Brittleness
(8) Corrosive resistance
(9) Abrasion resistance
(10) Fatigue
(11) Corrosion fatigue
(12) Machinability
(13) Hardness

c. It is used as a hardening element.

d. On the amount of carbon in the metal.

e. (1) Wrought iron
(2) Cast iron
(3) Steel
(4) Cast steel
(5) Steel forgings
(6) Alloy steels

f. (1) Aluminum
(2) Chromium
(3) Cobalt
(4) Copper
(5) Lead
(6) Magnesium
(7) Manganese
(8) Molybdenum
(9) Nickel
(10) Tin
(11) Titanium
(12) Tungsten
(13) Zinc

g. (1) Appearance/Chemical analysis
   (2) Fracture
   (3) Spark
   (4) Torch

h. Gray cast iron

i. Cast steel

j. Spark test

k. Carbon tool steel

l. Copper sulfate

m. Silver nitrate

n. Scleroscope test

REFERENCES

REFERENCES

The following documents were used as resource materials in developing this subcourse:

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TC 9 - 524

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