

SECTION 1, CHAPTER 6

METALLURGY

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Introduction

1. Engineering metals can be divided into two classes—those containing much iron are called ferrous metals, whilst those with little or no iron in their composition are called non-ferrous metals. Pure metals are little used in engineering practice; they rarely possess all the properties that are desirable, or even essential, for engineering work. The choice of a metal for the fabrication of a particular item is governed principally by the metal's properties of brittleness, conductivity, ductility, elasticity, fusibility, malleability, tenacity and toughness. Research has shown that the desirable properties of a metal may be improved by heat treatment or by alloying it with other metals or elements. This has led to the development of numerous alloys in both the ferrous and non-ferrous groups, each alloy possessing its own characteristics and being in one way or another superior to the base metal. This process of development is continuous and new alloys are constantly being sought.

Specifications

2. British Standard Specifications are issued by the British Standards Institution and, from time to time, each specification is reviewed to see if it can be improved in the light of experience. Each metal and alloy is produced to a particular specification. All the necessary information regarding composition, heat treatment required and physical tests applicable to each metal, or alloy, is given in its specification.

PROPERTIES OF METALS

Tenacity

3. Tenacity is the property of resisting fracture when subjected to tensile or stretching forces. Tensile strength is the measure of tenacity, and the ultimate tensile stress is usually stated as the smallest stress in tons, or lb., per square inch cross-sectional area which will break the material.

Elasticity

4. Elasticity is the tendency of a body to return to its original shape after having been stretched, compressed, or deformed within defined limits. If the stress is large enough,

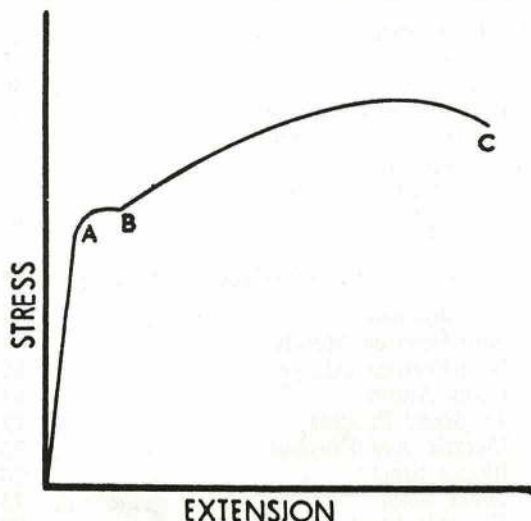


Fig. 1. STRESS-EXTENSION

the metal will be permanently deformed or fractured. In the accompanying approximate stress-extension diagram for mild steel (Fig. 1), the metal is elastic at stresses up to point A, which is called the elastic limit. The modulus of elasticity may be broadly stated as the theoretical stress which would double the length of a piece of the metal. For mild steel this is given as 13,000 tons per sq. in., but a much smaller stress would break the metal. If the elastic limit is not exceeded all steels stretch an equal amount for the same stress, but have different elastic limits.

Ductility

5. This is the property of metals which enables them to be mechanically deformed when cold. At point B, Fig. 1, which is called the "yield point", non-elastic stretch takes place and further increases of stress cause increases in length and decreases in cross-section which is called "ductile extension". Many non-ferrous metals are very ductile and have no definite yield point as shown in Fig. 2. Many materials become increasingly ductile when heated.

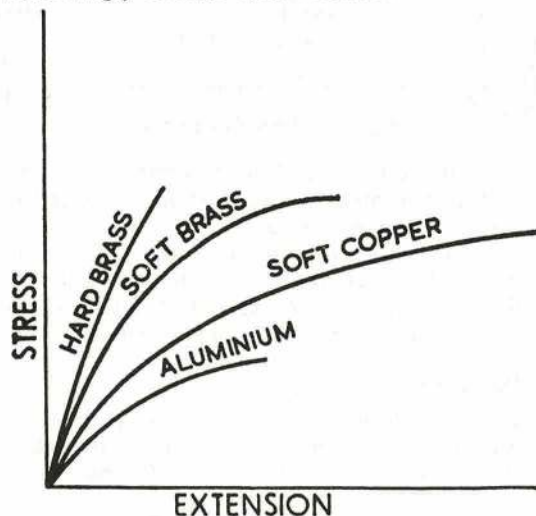


Fig. 2. NON-FERROUS METALS

Malleability

6. This is the property of being able to be mechanically deformed by rolling, forging, extrusion, etc., without rupture and without pronounced increase in resistance to deformation. It is possessed by lead, tin and zinc

at room temperature, and by other common metals when they are heated to a suitable temperature.

Plasticity

7. Plasticity is the property of flowing to a permanent new shape brought about by the application of mechanical force. Increase of pressure and temperature improve plastic flow.

Toughness

8. Toughness means the resistance to fracture by blows, bending, or twisting, and is a condition intermediate between brittleness and softness. It is indicated in tensile test by a high ultimate tensile stress and low to moderate elongation and reduction in area. It is also associated with high values in the impact test. Toughness decreases with heating.

Hardness

9. Hardness is the resistance to abrasion or deformation, and it is decreased by heating. It is measured by determining the resistance to indentation and is usually stated relative to the hardness of other materials.

Brittleness

10. Brittleness is the tendency to fracture without appreciable deformation and under low stress. A brittle material breaks easily under a sharp blow, although it may resist a steady stress quite well.

TESTING METALS

Introduction

11. Testing is necessary to ensure the suitability of metals for certain components and also suitability for the processes which will be used to produce the parts. The British Standards Institution has set up certain test standards and testing ensures that metals conform to their relevant specifications.

Analysis

12. Samples of the metal to be tested, in the form of filings or cuttings, are subjected to applications of heat and/or acids to confirm the presence and percentage of the constituents.

Etching

13. For this process, a test piece, with one of its faces highly polished, is submitted to the effect of an etching solution containing acid. The solution attacks the polished face and microscopic examination reveals the micro-structure of the metal.

Sulphur Print

14. It is often possible to show, by means of a sulphur print, the grain flow and the manner and distribution of impurities embedded in steel. Sulphur printing consists of soaking a sheet of bromide photographic paper in a 3 per cent. sulphuric acid solution, and then pressing it on a roughly polished forging. The sulphide present is attacked by the acid and the gas evolved attacks the bromide paper. Contact for two minutes is generally sufficient, the paper then being photographically fixed. Black lines on the paper indicate the grain flow and irregularities and inclusions are also revealed by dark areas.

Tensile Test

15. This is the most used test and from it the following information is obtained:—

- (a) Ultimate tensile strength.
- (b) Elastic limit.
- (c) Yield Point.
- (d) Percentage elongation.
- (e) Percentage reduction in cross-sectional area (taken at point of maximum necking).

16. The elastic limit is mainly of interest to the designer, but the production engineer will be more interested in the other four properties, for the elastic limit must always be exceeded when shaping is carried out. If the metal is to be machined, chipped, filed, etc., then the ultimate tensile stress must be exceeded. Usually, the higher the ultimate strength, the more power will be required to rupture the metal.

17. Stresses higher than the elastic limit, but lower than the ultimate tensile strength, must be used if the metal is to be forged, rolled or drawn. Rolling or drawing of cold mild steel is done in the ductile extension range. Heating reduces the elastic limit and ultimate tensile strength, so rolling and drawing stresses will also be reduced by the application of heat.

18. Cold ductility is indicated by elongation and reduction in area, and a guide to toughness is given by the ultimate tensile strength together with the percentage elongation.

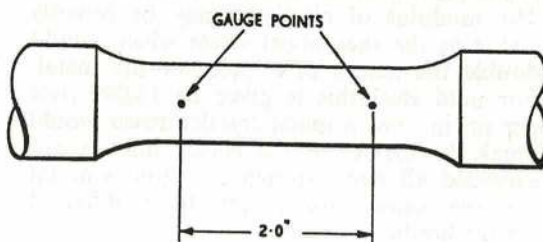


Fig. 3. TEST PIECE

19. The test is carried out on a tensile testing machine, using a standard test piece (Fig. 3). This has a cross-sectional area of 0.25 sq. in. and is secured by its ends in the machine. The machine stretches the specimen and provides readings of its increasing length with the loads applied. Two centre punch marks, usually 2.0 in. apart, are used to determine the extension. An example of a ductile metal just before breakage is shown in Fig. 4.

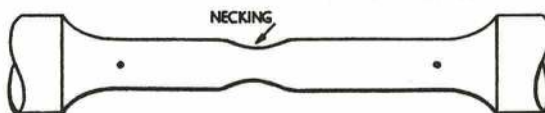


Fig. 4. NEAR BREAKAGE

20. The testing machine is sometimes made so that compression tests can also be carried out. Compression tests are usually confined to cast iron, timber, and non-ductile materials. Test pieces must be less than five diameters long, or the specimen will collapse by bending, and not by pure compression.

Bend Tests

21. These tests are used to assess the ductility and freedom from brittleness of a metal. A specification might require, "the bar to be

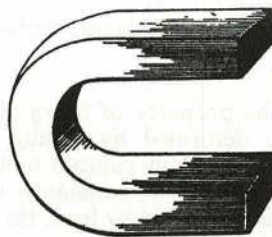


Fig. 5. BEND TEST SPECIMEN

bent through 180 degrees, the inner radius of the bend to be one and a half times the thickness of the bar". No cracks or fracture must occur.

22. The continuous or reverse bend test is applied with certain very ductile materials. A prepared piece of sheet metal is held between blocks which have edges of suitable radius for the gauge of the metal test piece. The projecting end of the test piece is then alternately bent and straightened through 90 degrees or 180 degrees. The number of bends required to cause fracture is taken as a measure of ductility.

23. The close bend test consists of turning over the corner of the sheet and closing it down on to a piece of the same gauge. No cracks or fracture must occur at the bend of the metal.

Hardness Tests

24. **Brinell.** The object of this test is to determine the comparative hardness of the metal. A steel ball of 10 mm. diameter is pressed into the specimen at a constant pressure for a definite time. The diameter of the impression is measured with a microscope containing a graticule or measuring scale. The diameter can then be compared with a numerical table from which the hardness number is read off; the smaller the impression, the higher is the hardness number. With steels and ferrous alloys, a pressure of 3,000 kilograms is applied, but when testing white metals, lead, aluminium and its alloys, a pressure of 500 kilograms is used. The time for which the load is applied is usually 15-30 seconds for 3,000 kilograms, and 30-60 seconds for 500 kilograms. It is possible to determine the approximate tensile strength of steels from the hardness number by the use of one of two constants. If the number is above 175, multiply by 0.21 and if below 175 by 0.23; in each case the product is tons per square inch. The Brinell machine has its limitations, for the ball makes a large impression which, besides being dangerous in a highly stressed part, makes the machine unsuitable for parts less than 0.50 in. thick.

25. **Vickers.** With this test, a diamond of pyramid shape is used instead of the ball. Brinell and Vickers numbers are identical for

soft and medium materials but Vickers numbers are higher for hard materials, and are considered more reliable.

26. **Rockwell.** A specially shaped indenter called a "brale" is forced into the material and the machine records the depth of the impression. The hardness number is then read on a dial on the machine. This test is suitable for mass inspection of parts. These tests only indicate the surface hardness of the metal.

Impact Test

27. **The Izod Impact Test.** The principle of the Izod or "notched-bar" impact test is shown in Fig. 6. It is used to find the shock resistance or toughness of the material. It will show the difference in impact value resulting from various heat treatments to the same steel. Small variations in heat treatment often show great differences in the physical properties, and this is particularly

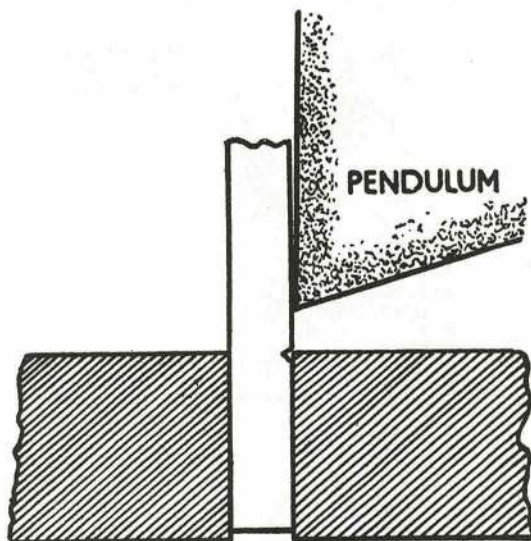


Fig. 6. IMPACT TEST

so with nickel-chrome steels. The tensile test may show no variation when different heat treatments have been applied, but the Izod test may reveal a great change in resistance to impact. The notched specimen, which is machined to standard dimensions, is held in a vice and a swinging pendulum breaks the test piece. The Izod machine registers the

initial energy and the energy after breakage, so that the energy required to break the test piece is directly indicated in ft. lb.

FERROUS METALS

Introduction

28. Ferrous metals, as has already been stated, are those metals which consist mainly of iron with comparatively small additions of other metallic or non-metallic substances. Crude iron is found in the form of iron ore, in which the pure metal is associated with a variety of other elements, mainly non-metallic. The first stage in the production of usable ferrous metals is the recovery of the iron, in a reasonably pure state, from the basic ore: this involves heating the ore in a blast furnace (Fig. 7), using coke as the fuel and limestone as a flux for separating some of the impurities. The iron is removed from the furnace in the molten state and is run into suitable sand and/or metal moulds known as 'pigs', the semi-refined metal thus obtained being termed pig iron.

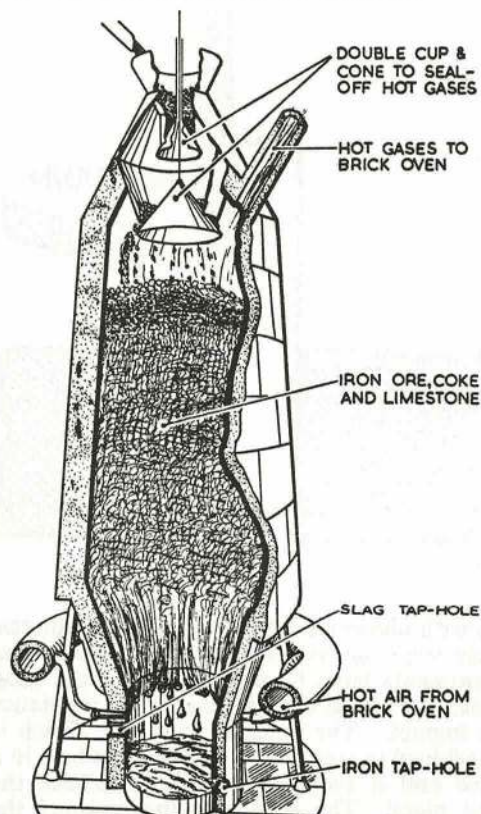


Fig. 7. BLAST FURNACE.

Pig Iron

29. Because of the impurities it contains, pig iron is not suitable for engineering purposes, but it is the basic material from which cast-iron, wrought-iron and steel are produced. Principal impurities are carbon, silicon, manganese, sulphur and phosphorus. Its composition varies according to the ores used, the smelting practice and the purpose for which the iron will be used.

Impurities

30. **Carbon.** Cast iron (the general name for iron that has been re-cast from pig iron) contains graphitic (free) carbon and iron carbide (combined carbon). The grey colour of fractured cast iron is due to the flakes of graphite, as also is its "dirtiness" when being filed.

31. **Silicon.** This is a non-metallic element which is used to soften cast iron. The free carbon is increased and the combined carbon decreased when the amount of silicon is increased.

32. **Manganese.** This is a hard, brittle, metallic element. Sulphur is dangerous if present as iron sulphide so sufficient manganese should be present to take up the sulphur content.

33. **Sulphur.** Sulphur is invariably present, being picked up from the coke used in smelting. It increases brittleness, because it has a lower melting point than iron or steel and it finally solidifies in the grain boundaries. Also, at correct forging temperatures the iron sulphide is melting, and when forging begins the metal fractures at the grain boundaries and is said to be "hot short".

34. **Phosphorus.** This is a non-metallic element which is always present in cast iron. It is not so dangerous as sulphur but, by forming iron phosphide, it increases the brittleness of cast iron. The amount is kept as small as possible, except in light, intricate castings where increasing the amount improves the flow of molten cast iron.

Production Cast Irons

35. Cast iron is one of the most commonly used metals. In the molten state it pours

fairly easily into moulds. It does not require annealing as its internal structure when cold is sufficiently free of stresses. In order to produce a machineable but strong casting, having about 0.5 per cent. combined carbon, the foundry has to strike a balance between the amounts of manganese and silicon. Light castings cool quicker than heavy ones, which makes them harder, due to the increase of combined carbon (iron carbide) and the decrease of free carbon (graphite). More silicon is, therefore, required for light castings to increase the formation of graphite. The required composition is obtained by mixing pig irons and scrap cast iron by weight before charging the cupola.

Malleable Cast Iron

36. Pig iron used in the foundry is called "grey" iron, but white and mottled pig irons are also produced. These have up to 3.5 per cent. combined carbon, but little or no free carbon, so the metal is hard and un-machineable, but casts very well. Consequently, castings made of white or mottled iron are softened and made malleable by special heat treatment and contact with a substance containing iron oxide, e.g. hematite ore.

Wrought Iron

37. Wrought iron is produced by the "puddling" process. It is iron which contains only a very small amount of other elements, but containing 1.3 per cent. by weight of slag in the form of particles elongated in one direction, giving the iron a characteristic grain (Fig. 8). It is more rust-resistant than mild steel and welds more easily. Wrought iron will withstand repeated shock loads without becoming seriously brittle, but occasional annealing is recommended. It is used for chains, hooks, etc.

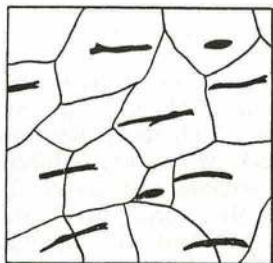


Fig. 8. WROUGHT IRON

Plain Carbon Steel

38. Carbon steel is a steel whose properties are determined primarily by the percentage of carbon present. Steel contains no free carbon, the carbon always being present as iron carbide. As the carbon content is increased, the steel becomes harder and stronger, but less ductile and shock resistant (Fig. 9). The carbon in steel is limited to the amount which will remain combined after any standard heat treatment and, in practice, 1.5 per cent. is rarely exceeded.

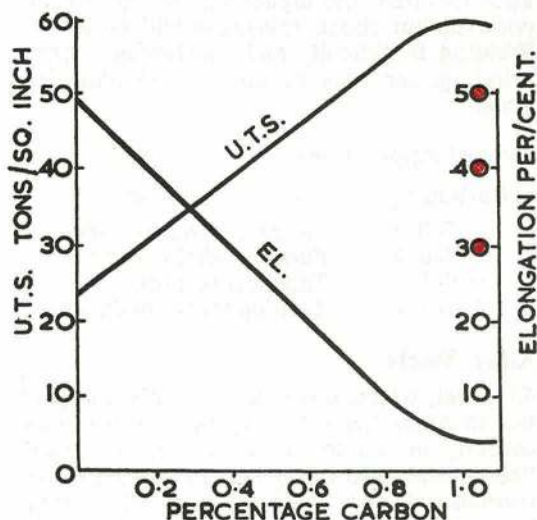


Fig. 9. PROPERTIES OF STEEL

39. **Dead Mild Steel.** Containing up to 0.1 per cent. carbon, this is the softest and most ductile steel. After hot rolling into sheets, it is suitable for producing light articles by cold working. It is used for rivets and solid-drawn tube. It welds excellently and machines readily.

40. **Mild Steel.** Contains carbon from 0.1 to 0.35 per cent. Its properties are similar to dead mild steel up to 0.2 per cent. carbon, but it is much harder and stronger though less ductile with 0.3 per cent. carbon. A large proportion of the total steel produced is in the range 0.2–0.35 per cent. carbon. Welding properties and machineability are good.

41. **Medium-Carbon Steel.** Having an increased carbon content of 0.35–0.65 per cent. increases the strength and hardness,

but ductility decreases. Steel with 0.4-0.5 per cent. carbon is used for axles and shafts which are heavily loaded, and also have to withstand abrasion. Welding properties and machineability become poorer with more than 0.4 per cent carbon.

42. High-Carbon Steel. This steel contains 0.65-1.5 per cent. carbon and generally covers the many different tool steels which are used in the heat-treated condition. Their properties vary widely with the heat treatment given. The more abrasion resistance required, the higher will be the carbon content, but shock resistance will be lower. Welding is difficult, and machining, except grinding, can only be done in the annealed state.

Typical Applications :

Carbon, %	Uses
0.7-0.8 ..	Springs, hammers, dies.
0.8-0.9 ..	Punches, drills, shears.
0.9-1.1 ..	Taps, drills, axes.
1.1-1.4 ..	Turning tools, small cutters.

Alloy Steels

43. Steel, which owes its distinctive properties to some element or elements other than carbon, or jointly with carbon, is called "alloy steel" and it is generally low in carbon content. A very wide range of alloy steels has been developed to meet the varying conditions to which engineering parts are subjected. Tensile, compressive and shear forces may all be present and may be accompanied by heat, as in the internal combustion engine, or chemical corrosion by liquids and gases.

44. Nickel Steel. If 3 per cent. nickel is added to mild steel, it increases the strength and shock resistance of the steel. Nickel is only added to steel of low carbon content, as it tends to change iron carbide to graphite when the steel is being heat treated. Case-hardening nickel steel contains 3 per cent. nickel and 0.15 per cent. carbon. Steel containing 36 per cent. nickel and 0.2 per cent. carbon is called 'Invar'; it is non-magnetic, stainless and expands very little when heated.

45. Chrome Steel. Chromium and nickel are usually found together in steel, because chromium counteracts the tendency of nickel

to form graphite in steel, and nickel counteracts the tendency of chromium to promote coarse grain structure. A steel with 3.5 per cent. nickel, 0.75 per cent. chromium and 0.3 per cent. carbon, gives a yield point more than three times that of mild steel, and enables the metal to withstand much higher stresses. Heavily loaded shafts, high tensile bolts and parts for high speed engines where weight must be kept low, are made of this and similar types of steel. Air-hardening nickel chrome steel contains 4.25 per cent. nickel, 1.25 per cent. chromium and is used for some tools and gear wheels.

46. Stainless Steel. Corrosion resistance is greatly increased if not less than 13 per cent. chromium is added to steel. Stainless steel turbine blades are often made of steel with 13 per cent. chromium and less than 0.1 per cent. carbon and, owing to the low carbon content, it is often called stainless iron. Steel containing 18 per cent. chromium and 8 per cent. nickel, if heated and quenched is quite soft and can be cold worked.

47. Molybdenum Steel. Molybdenum is often added to nickel chrome steels to prevent temper brittleness if the steel is to be held between 250° and 500° C.; 0.5 per cent. is sufficient to overcome this trouble. It has also been used as a partial substitute for tungsten.

48. Tungsten Steel. The addition of tungsten makes steel retain its hardness at high temperatures, and so it has been applied to internal combustion engine exhaust valves, but its main application is for high-speed cutting tools. Some tungsten steel alloys are called high-speed or self-hardening steels, since they may be heated to 600°C. without lowering the hardness. Intermittent heating to this temperature tends to harden the metal.

49. Vanadium Steel. A small amount of this element may be added to steel to improve resistance to fatigue. Steels which contain about 0.25 per cent. of vanadium possess a very high elastic limit and are very tough. Steels which are subjected to high alternating stresses and severe shocks, such as engine valve spring steel, may contain about 0.2 per cent. of vanadium. Front axles of road vehicles are quite frequently steel forgings containing a small amount of vanadium.

50. Cobalt Steel. The addition of cobalt to a high-carbon steel produces an alloy with exceptional magnetic properties. A permanent magnet made of 35 per cent. cobalt steel has a magnetic "field" about three times as intense as that of a tungsten alloy magnet and about eight times that of a high-carbon steel magnet. Cobalt also improves high-speed tool steels, and is mainly used for tipped tools.

51. Manganese Steel. Manganese is included in all steels to counteract the bad effects of sulphur. Steel becomes extremely hard and tough when manganese from 11-15 per cent. is present. It is non-magnetic and very difficult to machine.

NON-FERROUS METALS AND ALLOYS

Introduction

52. Certain non-ferrous metals, such as copper, lead and aluminium, are used in the commercially pure state for specialized engineering purposes, usually in the form of sheets, tubes and wires, or as thin coatings on other metals. Precious metals, such as platinum and silver, are used in very small quantities for highly-specialized work, e.g. in the highest grades of electrical instruments. Nickel, chromium, cadmium and zinc are used in the form of electrically-deposited coatings on other metals to minimize corrosion; tin and zinc coatings on steel sheets are made by dipping the sheets into the molten metal; zinc and some other non-ferrous metals can be sprayed on to metallic surfaces to form protective coatings. Mercury, the only metal that is liquid at room temperatures, is used in thermometers and certain types of barometers and pressure gauges. In addition to such 'pure-state' uses, non-ferrous metals are of much importance as alloying agents in ferrous metals, and as base metals and alloying agents in the many non-ferrous alloys.

Non-Ferrous Metals

53. Aluminium. Aluminium is a light, ductile metal possessing high electrical conductivity and good resistance to corrosion. It is obtained from bauxite and is the basis of light alloys. It can be worked by any of the common processes such as rolling, spinning,

drawing, stamping, tapping, forging, extruding and machining. It can be welded, but soldering should not be attempted. It is tin white in colour and melts at 657°C.

54. Antimony. This is a very brittle, bluish-white metallic element which melts at 630°C. It is an essential constituent in bearing metals (3-20 per cent.), and storage battery plates (4-12 per cent.), etc.

55. Copper. Copper is reddish brown in colour and melts at 1,085°C. It is sufficiently ductile to allow heavy cold work, and is annealed by heating to a dull red (650°C.) and quenching in water. It is a good conductor of electricity and heat, and has good resistance to corrosion. It is widely used for electrical purposes, tubing, bearing alloys, etc., and it is the basis of brass, bronze, aluminium bronze and other alloys.

56. Tin. This metallic element is white in colour with a yellowish tinge, and it melts at 232°C. It is soft and has good resistance to corrosion. It is widely used as a coating on steel (tin-plate) and is an important constituent of solder and white metal bearing alloys.

57. Lead. Lead is a bluish-grey, metallic element and is the heaviest and softest of the common metals; its melting point is 327°C. Lead has very good resistance to corrosion. It is used for plates in lead-acid batteries, and is a constituent of bearing metals, solder, etc.

58. Nickel. This is a silver-white metallic element which melts at 1,450°C. It is an important constituent of various alloys, and is also used for electro-plating.

59. Chromium. Chromium is a hard, grey metal which melts at 1,630°C. It is widely used as a constituent in many alloys and is also used as a corrosion-resisting plating.

60. Zinc. This is a white, metallic element with a bluish tinge; its melting point is 419°C. Because of its resistance to atmospheric corrosion, it is used for protecting steel (galvanizing, sherardizing, etc.). It is also used in the form of sheet and as a constituent in alloys, zinc base alloys being widely used for example in the motor industry.

Non-Ferrous Alloys

61. **Brass.** Brass is primarily an alloy of copper and zinc, but other elements such as aluminium, iron, manganese, nickel, tin and lead, are frequently added. Lead is usually added to improve the machining properties, and tin and nickel to improve the polish.

62. **Bronze.** This is primarily an alloy of copper and tin, but the name is now applied to other alloys not containing tin, e.g. aluminium bronze and manganese bronze. Phosphor-bronze usually contains 10–14 per cent. tin and 0.1–0.3 per cent. of phosphorus, with or without additions of lead and nickel, and it is used for bushings and high duty bearings. Leaded bronze is a copper base alloy containing 5–10 per cent. of tin and 8–20 and sometimes 30 per cent. of lead. This is used for heavy duty bearings, being widely utilized in compression ignition engines.

63. **Soft Solders.** These are mainly alloys of tin and lead, to which a little antimony is often added to give a harder and stronger joint.

64. **Brazing Spelter.** The alloys used for brazing are composed mainly of copper and zinc. A common brazing spelter is made up of 50 per cent. copper and 50 per cent. zinc, and has a melting point of 880°C. Increasing the zinc content lowers the melting point.

Light Alloys

65. **Duralumin.** This is an aluminium base alloy containing copper, magnesium, manganese and silicon up to 0.7 per cent. It has the property of age-hardening during a period of three to four days after quenching from 500°C. It has a marked resistance to corrosion when fully age-hardened, and this property can be improved by a process known as "anodizing". Duralumin is almost as strong as mild steel and is widely used in sheet form; when both sides of the sheet are coated with pure aluminium it is known by the trade name of 'Alclad': this combines the properties of duralumin with the resistance to corrosion of aluminium.

66. **"Y" Alloy.** This alloy was developed by the National Physical Laboratory, the base metal, aluminium, being alloyed with

copper, nickel and magnesium. It was first used for castings, but is now generally used in the forged and heat treated condition. It is widely used for the manufacture of pistons.

67. **Hiduminium.** This is an aluminium alloy of the duralumin type. It is as strong as mild steel and can be cast or wrought. It requires low temperature heat treatment to age-harden. It is used for pistons, cylinder heads and, on some engines, for connecting rods.

68. **Magnesium Base Alloys.** These alloys, which are generally produced under such trade names as 'Elektron', use magnesium as the base metal, with aluminium, zinc, manganese, etc., as the alloying elements. They have a tensile strength of about 13 tons per sq. in., are lighter than the standard aluminium alloys, and can be cast, rolled, or forged. Special treatment is necessary to combat corrosion.

MANUFACTURE OF STEEL

Introduction

69. Steel is produced from pig iron, the processes being essentially methods of ensuring that the steel contains known amounts of carbon, manganese and any other desired alloying elements. Phosphorus must not exceed 0.1 per cent. in steel, therefore, if the phosphorus content is to be reduced, the furnace has a basic refractory lining (magnesite or dolomite) which reacts with the phosphorus and removes it. Pig iron produced from high grade hematite ore contains little phosphorus, so the furnace has an acid refractory lining (silica), which does not reduce the phosphorus content.

Open-Hearth Process

70. This is a process for making steel from varying proportions of pig-iron and scrap, and most of the steel used today is produced in this way. The charge, which is on a shallow hearth, is melted by burning gas over it (Fig. 10). After a period up to fourteen hours, the impurities have been removed and the metal is ready for pouring. In the acid process the furnace is tapped when the carbon content is correct, but in the basic process the carbon content is corrected by adding anthracite coal during pouring. Additions of manganese and silicon are also made in

the ladle to deoxidize the steel. The molten steel is poured into suitable sand moulds for steel castings, or into ingot moulds if required for the rolling mills or forges.

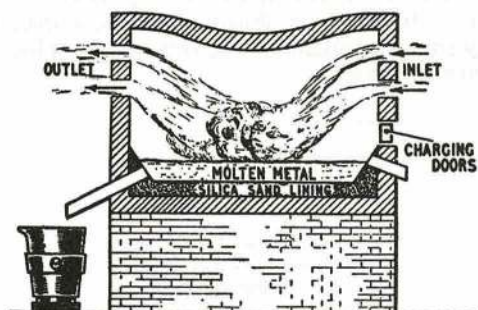


Fig. 10. OPEN-HEARTH FURNACE

Bessemer Process

71. The bessemer converter (Fig. 11) is used for this, the oldest method of producing steel in large quantities. The steel is made by blowing air through molten pig-iron, and the oxygen in the air combines with the silicon, phosphorus, carbon and manganese in the iron and burns them. The "blow" must be stopped after about 20 minutes to stop combination of the iron with the oxygen. This point is very critical, the margin of error being a matter of seconds. The charge is then recarburized and deoxidized by the addition of compounds of iron, manganese and carbon. The process may be acid or basic, according to the lining of the converter.

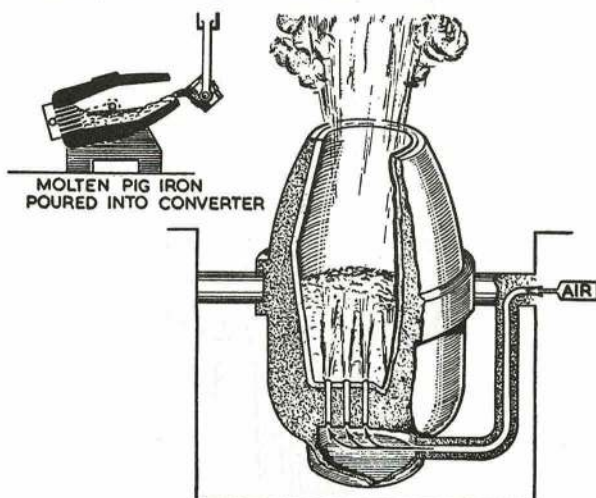


Fig. 11. BESSEMER CONVERTER

Tropenas Process

72. The converters used for this process are usually small, the air being blown across the surface of the molten metal.

Electric-Arc Furnace

73. The furnaces mentioned previously are coke or gas-fired but electricity is also widely used. The electric furnace usually has two or more electrodes above the metal, the arc being struck between the metal and the electrodes. Higher temperatures and closer control of the carbon content of the steel is possible than with coke or gas-fired furnaces.

Blister Steel

74. This is produced by packing wrought-iron bars with charcoal and heating to a yellow heat for a number of days. Carbon from the charcoal passes into the iron and the bars have a blistered appearance when removed from the furnace. Blister steel is the raw material for tool steels.

Shear Steel

75. Blister steel bars are heated, forged and then piled together. The piles are reheated to a white heat at which they weld together and are then forged to produce single-shear steel. Double-shear steel is made by bending the bar of single-shear over on itself and re-forging; this produces a very high quality tool steel.

Crucible Steel

76. Crucible steel is made by melting blister bar, or wrought iron, charcoal and ferro-alloys in fireclay crucibles. The crucibles may be heated by coke, gas or oil firing, or by electrical induction (Fig. 12) which is the

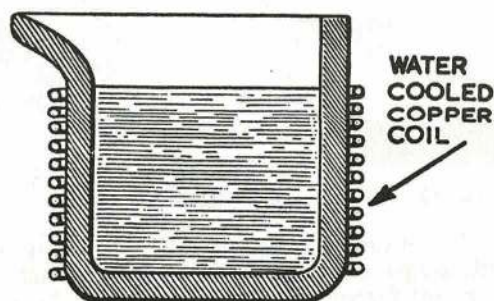


Fig. 12. ELECTRIC CRUCIBLE

most efficient. The steel is deoxidized in the crucibles before pouring. The raw materials must be of high quality, because sulphur, phosphorus, etc., are not removed during this process. Most high grade tool steel is produced by this method and is called crucible cast steel.

PROCESSING OF METAL

Introduction

77. Some manufacturing processes are carried out when the metal is hot and some when the metal is cold. Heating the metal increases its ductility and malleability and reduces tensile strength and toughness, so the metal is more easily shaped than if it were to be cold. The best hot working temperature ranges have been found by experience for the different metals. Forging and rolling are the two main hot working processes.

Forging

78. Forging is the operation of shaping hot metal by means of hand hammers for small work, and power operated hammers or presses for large work. The size of section which can be worked by hammering is limited and hammering tends to deface the work. The hydraulic press, which is usually used for large forgings, squeezes the hot metal, thus working the metal right through to the centre.

79. In drop forging, a "blank" of hot metal is forced to shape by a pair of dies. The upper die is fixed to the head of a drop hammer, and when the two dies meet, if the blank has the correct volume, it will exactly fill the die space.

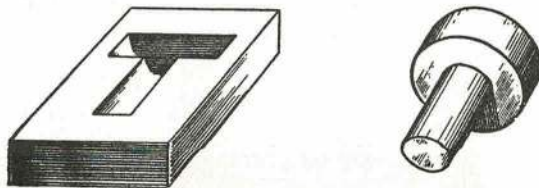


Fig. 13. LOWER DIE AND COMPONENT

80. To ensure exact filling, the blank is a little larger than the die space; the "flash" (Fig. 14) formed by the excess metal being removed later. Machining may not be necessary, as drop forgings can be produced

with a good finish, and to quite accurate dimensions. The process has certain limitations, such as suitability of shape of the part, and also the number of parts required must be sufficient to warrant the cost of the dies. Internal combustion engine connecting rods and spanners are typical examples of drop forgings.

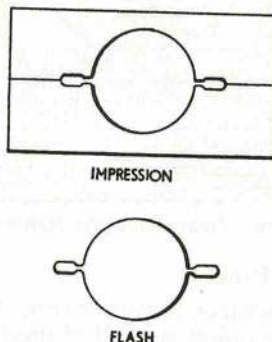


Fig. 14. IMPRESSION-FLASH

81. Forging should be done so as to take advantage of the altered internal structure of the metal, as shown in Fig. 15. If a force is applied in the direction of the arrow F, the forged part will be the stronger of the two. The structure of the metal will also be re-

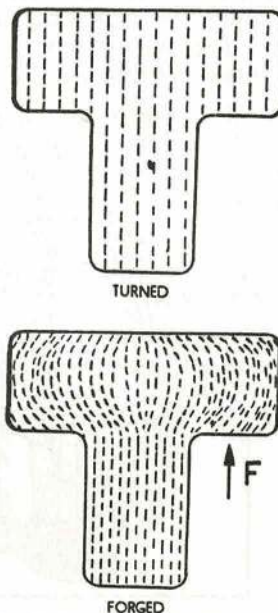


Fig. 15. TURNED-FORGED

finer and improved, if forging is done in the correct temperature range. The following example shows the improvement in mechanical properties produced by correct forging of mild steel.

Property	Original Ingot	After Forging
U.T.S. tons/sq. in. ..	26	30
Elongation on 2 in. %	14	35
Red. in area % ..	10	50
Izod Impact ..	6	28

Rolling

82. The majority of mild steel parts are made from rolled sections, a good example being sheets for vehicle bodies. Rollings start as a cast steel ingot, which is reduced in cross-section by a cogging mill (Fig. 16). The ingot is passed to and fro between the rolls and produces, when the cross-section is more than 36 sq. in., a series of "blooms", smaller sizes being called "billets". Plate or sheet is produced by continued rolling until the desired thickness is obtained. Bars or structural sections are produced by shaped rollers which, by a series of "passes" through the rollers, gradually reduce the cross-section to the final shape.

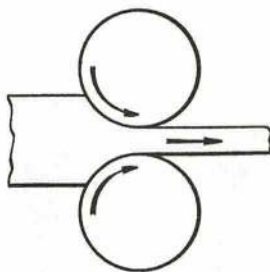


Fig. 16. COGGING MILL

83. Hot working has several disadvantages, because hot metal readily oxidizes and the surface of the metal is dull and "scaly". If reheating is required, it may be inconvenient owing to size and shape. Some metals are "hot short", which means that they become brittle and may fly to pieces when hot worked. Steel which contains too much iron sulphide is prone to hot shortness.

Casting

84. The oldest form of shaping metal is by casting and most metals are still melted and cast from ores. Metal or wood patterns have

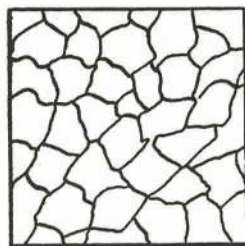
their shape reproduced in some material like damp sand and the "mould" dried before molten metal is poured into it and allowed to solidify.

85. Pressure diecasting is a process by which precision castings of various alloys are made. Liquid metal is fed under pressure into a metal die or mould. This process is suitable for mass production only, as the machines and dies are expensive. Carburettors made of zinc base alloy are a good example of this type of production.

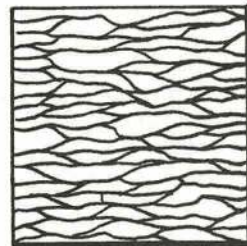
86. **Chilling.** If a casting is required with a hard durable surface, it is obtained by chilling. The mould is wholly or partly made of iron, sometimes water-cooled, and this accelerates cooling, so giving greater hardness. Uniform hardness throughout a casting is obtained by careful chilling of the thicker parts, so obtaining even cooling, which also reduces internal stresses set up by the contraction of the metal.

Cold-Working Processes

87. Cold working is the operation of shaping metal at or near atmospheric temperature by rolling, pressing, drawing, stamping or spinning. The crystalline structure of the metal is deformed and work-hardening occurs. The grains are flattened and lengthened (Fig. 17) in the direction in which the metal is drawn out.



Normal Structure



After Cold Work

Fig. 17. GRAIN STRUCTURE

88. The danger of cracking increases during cold working, due to the increased hardness. The increased hardness and tensile strength may be an advantage, if cold working is not severe and the part is only lightly stressed. It may be necessary to anneal the metal at some stage during the work if considerable cold work takes place. Heating will introduce the scaling difficulty, unless special

furnaces for bright annealing are used. The surface of the metal is very important, for, if scale is worked into the finished part, it might easily cause failure of the part in service. Consequently, some method of surface cleaning is usually used before cold working takes place.

89. Cold Rolling. A four-high mill (Fig. 18) is used for cold rolling strips and sheets. Any deflection and consequent change of thickness of the strip or sheet is prevented by the large rolls. The surface of the metal is very smooth and the thickness can be maintained within very accurate limits.

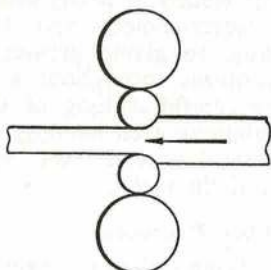


Fig. 18. FOUR-HIGH MILL

90. Tube Drawing. For this operation, the billet is a cast or hot-forged tube which is supported internally by a mandrel, and is drawn through a series of dies, each draw reducing the wall thickness and increasing the length of the tube (Fig. 19). Smaller mandrels are introduced until the desired tube diameter is obtained. Rod and wire are drawn in a similar manner, but the mandrel is not required.

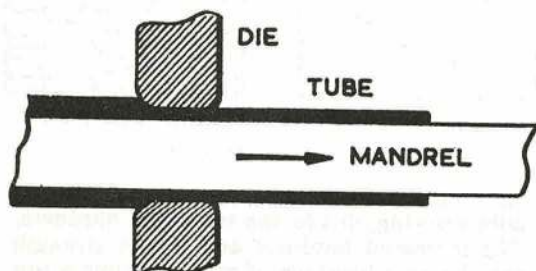


Fig. 19. TUBE DRAWING

91. Pressing. This operation is one of the most important mass production processes. The metal is stretched, but not greatly reduced in thickness by means of press tools.

The blank is held firmly by the outer punch and the inner punch produces the required shape (Fig. 20). Some machines punch out the blank and perform the pressing in one operation from sheet metal, and many complex shapes are produced.

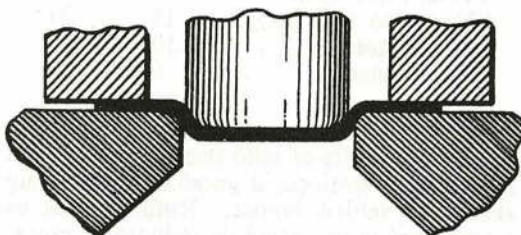


Fig. 20. PRESSING

92. Deep Drawing. The process of cold-working or drawing sheet or strip metal by means of dies into shapes involving considerable plastic distortion of the metal; e.g. motor vehicle mudguards. The operation is similar to tube drawing, and is carried out on a press (Fig. 21). Heavy pressures are required, as there is a big reduction of the thickness of the blank which is called "ironing".

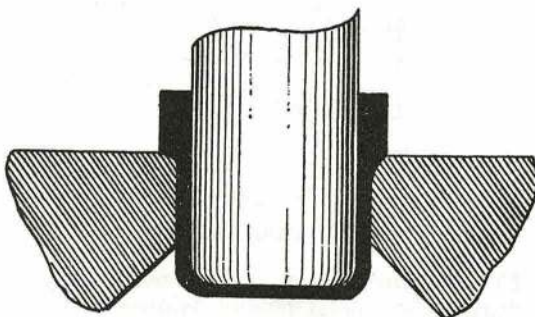


Fig. 21. DEEP DRAWING

93. Spinning. This operation consists of shaping sheet metal to the contour of a former by the pressure of a blunt tool applied to it whilst revolving in a lathe (Fig. 22). The former is held in the lathe headstock, thus being rotated, whilst the sheet is held up against it by a "palette" fitted in the tailstock. The sheet is kept lubricated with tallow, and the tool is used to gradually force the sheet to the shape of the former.

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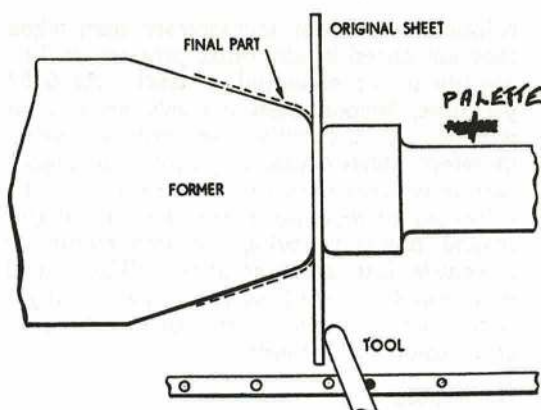


Fig. 22. SPINNING

94. Cold Heading. This is the process of forming the heads of bolts, rivets, etc., without heating the metal. A suitable piece of wire forms the blank, and one end is cold forged in dies to form the desired shape of the head. Annealing may be required after cold heading.

THEORY OF HEAT TREATMENT OF PLAIN CARBON STEEL

Introduction

95. Plain carbon steel owes its properties to the presence of carbon. Steels which owe their properties to elements other than carbon are termed alloy steels. The effects of carbon when added to iron are best understood by first considering pure iron. Pure iron is very ductile, and has a tensile strength of 18 tons per sq.in. The addition of carbon to the iron increases the tensile strength, hardness and brittleness, and at the same time decreases the ductility (0.87 per cent. carbon steel has a tensile strength of approximately 55 tons per sq. in.). The increase in strength of steel with increase in carbon content is limited to the amount of carbon which will remain combined with the iron after any normal heat treatment. Above

1.7 per cent. carbon, the excess carbon is in the form of free (uncombined) carbon or graphite, which has very low strength. The carbon content of plain carbon steel rarely exceeds 1.5 per cent.

96. The internal structure of steel may be varied by heating and cooling, therefore, to produce certain properties in the steel, it is subjected to processes termed heat treatment. It is not always possible to produce all the desired properties in the metal and a compromise has to be made. Considerations of easy manufacture may necessitate softness of the metal, while requirements of use may demand great strength and considerable hardness. Thus, if a steel is required to be hard and tough, the maximum degree of hardness and toughness cannot be obtained together, since maximum hardness promotes brittleness and maximum toughness generally reduces hardness.

Micro-Structure

97. The constituents of a carbon steel are pure iron (ferrite), and a chemical compound of carbon in iron termed iron carbide (cementite). In a low carbon steel (Fig. 23), these constituents when viewed through a microscope, appear as a laminated structure (pearlite), surrounded by free ferrite. With increasing carbon content, the proportion of pearlite to ferrite increases until, with a 0.87 per cent. carbon content, the steel becomes wholly pearlitic. Above 0.87 per cent. carbon content, a microscopic examination reveals pearlite surrounded by free cementite. Ferrite is soft, ductile, and not very strong; pearlite is strong and tough, but soft enough to be readily worked; cementite is very hard and brittle. Thus, as the carbon content is increased up to 0.87 per cent., the steel gets tougher and stronger, but beyond this percentage, due to the increasing cementite content, the steel becomes very hard and progressively brittle.

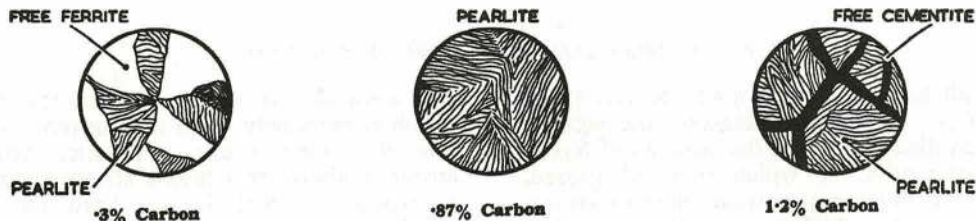


Fig. 23. MICRO-STRUCTURES OF PLAIN CARBON STEEL

Critical Points

98. When steel is heated, its temperature does not increase at a constant rate. The temperature rise, after proceeding steadily, is momentarily checked, and, after the period is passed, the temperature continues to rise as before. During this period of arrest, the metal absorbs heat, but instead of raising the temperature, the heat brings about certain changes in the metal. The temperature at which these periods occur are termed "critical" or "arrest" points.

99. In the equilibrium diagram (Fig. 24), the critical points are shown on a rising temperature. The line AEB represents the lower critical points, and the line DEC the upper critical points. It will be seen that although the steels vary in carbon content,

solution at a lower temperature than when they are mixed in any other proportion, i.e., pearlite is the eutectoid of steel. As 0.87 per cent. carbon steel consists entirely of pearlite, it has only one critical point, therefore, steels containing a lower or higher carbon content than 0.87 per cent. must be subjected to increase in temperature (upper critical point) to bring the free ferrite or cementite into solid solution. When steel is allowed to cool slowly, these changes occur in the reverse order, but at a temperature some 30°C. lower.

Hardening

100. When a carbon steel is heated to a temperature a little above its upper critical point, then cooled by drastic quenching, the normal structural change does not occur

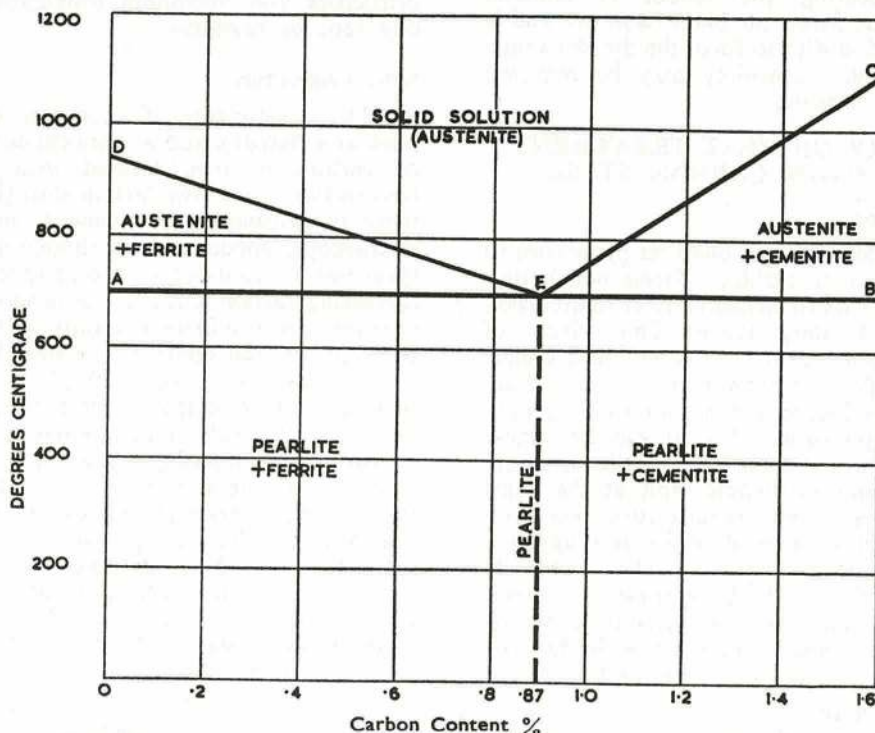


Fig. 24. IRON-CARBON EQUILIBRIUM DIAGRAM

they all have the same lower critical point (730°C.). At this temperature, the pearlite as such disappears and the laminae of ferrite and cementite, of which it is composed, dissolves and forms a solid solution known as austenite, which is non-magnetic. The ferrite and cementite of pearlite are in such proportion that the mixture forms a solid

the austenite is changed into martensite which is extremely hard and brittle. If the rate of cooling is not so drastic, then the austenite transforms into a structure known as troostite, which is less hard but very tough. An even slower rate of cooling will produce sorbite, a fine-grained structure which combines strength with ductility.

This hardening effect upon carbon steels is only slightly apparent with 0.25 per cent. carbon content, appreciable with 0.6 per cent., and almost attains its full value in a 0.87 per cent. carbon steel. Thus the degree of hardness of a steel is dependent upon its carbon content and the rate of cooling.

Tempering

101. Martensite is stable only at temperatures below 200°C. With increasing temperature, martensite is slowly modified first into troostite, and then into sorbite. Producing these changes in the steel with low temperature heat treatment is known as "tempering". The higher the tempering temperature—it is always below the lower critical point—the less the hardness and the greater the toughness of the steel.

Annealing

102. A steel, in a hardened or tempered condition, can be restored to its softest state by heating it to its upper critical point, thus bringing it to its austenitic condition, and then allowing it to cool very slowly by leaving the steel in the hot ashes or in the furnace after the source of heat has been removed. The slow cooling allows the normal structural changes to take place, and the steel reverts to its pearlite and ferrite, pearlite, or pearlite and cementite condition.

Normalizing

103. When steel is cold-worked, hammered, bent, rolled, etc., its crystal structure is disturbed; stresses and strains are set up and the metal becomes embrittled and weakened. Normalizing restores the crystalline structure to a normal condition and relieves such stresses and strains. The process is carried out by heating the steel slowly to its annealing temperature and then allowing it to cool freely in the air. This more rapid rate of cooling, as compared with the cooling rate in the annealing process, gives the steel a finer grain structure than does annealing.

Refining

104. Prolonged heating at temperatures well above the upper critical point followed by slow cooling—as happens during the process of case-hardening—causes the grain structure

of steel to coarsen, reducing toughness and strength. The refining process, which has the effect of reducing in size the crystalline structure, consists of re-heating the material to a specific temperature, generally between 840°C. and 900°C., followed by rapid cooling either in water or oil. This process may be carried out two or three times if desired, each heating being at a lower temperature than the previous one, and finishing with the final operation of hardening the skin or case of the steel by heating to about 760°C. and quenching in oil or water.

PRACTICAL HEAT TREATMENT OF PLAIN CARBON STEEL

Introduction

105. The range of alloy steels is so great that it is impracticable to include separate information on their heat treatment. If it is necessary to heat-treat an alloy steel, information must be obtained from the specification as the indiscriminate heating and cooling of such steel may result in the desired properties not being obtained. The following paragraphs describe the heat treatment of plain carbon steels which may or may not apply to alloy steels.

Methods of Heating

106. Steel should be heated slowly and uniformly, and, as the temperature to which steel is heated is one of the factors determining the success of any heat treatment, it is preferable to use heating equipment which permits rigid control of the temperature. Muffle furnaces or ovens, usually heated by oil, gas or electricity, are clean to use, capable of a high degree of heat and can be left at any given temperature without fear of overheating. The use of the blacksmith's forge is not a good method of heating as temperature control and uniform heating are difficult to maintain; unless great care is taken, the metal may become overheated and burnt. When using a blacksmith's fire, heat the job, if possible, in a steel tube and not directly in the flame. Baths heated by oil or gas and containing low melting point alloys or molten salts provide a good method of heat-treating steel. The heating is clean, uniform, under strict control, and irregular shapes can be heated throughout without over-heating. Various salts may be used

in the bath according to the range of temperature required.

Salts used in a Salt Bath (Proportion by weight)	Temperature (Centigrade)
Barium Chloride 100 per cent.	1,050-1,325
Barium Chloride 67 per cent. Potassium Chloride 33 per cent.	750-1,100
Sodium Chloride 50 per cent. Potassium Chloride 50 per cent.	650-900
Potassium Nitrate 50 per cent. Sodium Nitrate 50 per cent.	250-580

Measurement of Temperature

107. For measuring the temperature of the bath, furnace or oven, some form of thermometer is used. The "thermo-electric" thermometer (Fig. 25) embodies the "thermo-couple" principle, i.e. if two wires or the ends of two strips of dissimilar metal are joined and the junction is heated, a small electric pressure is generated. With increase in temperature, there is a corresponding increase in electric pressure. Connected to the free ends of the wires or strips is a millivoltmeter, which has a scale calibrated to read degrees centigrade. The instrument is situated close to the heating apparatus, the

temperature is within the normal tempering range, by the colour of the oxide film which forms on its surface. Although the results obtained are satisfactory for forging operations,

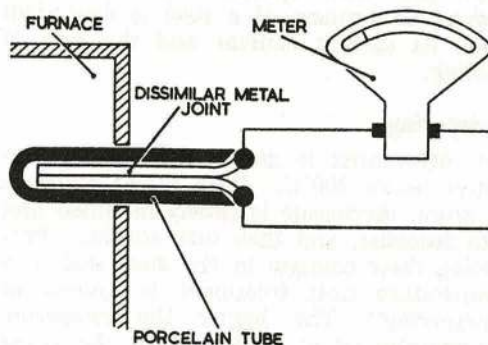


Fig. 25. THERMO-ELECTRIC THERMOMETER

and the hardening and tempering of a single tool such as a cold chisel, the heat treatment of steel should be done by more accurate methods of measuring temperature.

Cooling

109. The usual quenching media in order of rapidity of effect are brine, water, oil and air. When water is used as a quenching medium,

Colour of Steel	Approx. Temperature °C.	Steel to be Heat-treated
Dazzling white	1,400-1,500	"High-speed" tungsten steel.
Brilliant white	1,300-1,400	
White	1,200-1,300	
Pale yellow	1,100-1,200	
Yellow	1,000-1,100	
Orange	900-1,000	Austenitic chrome nickel stainless steel. High chromium stainless steel. Low carbon steel, and nickel chrome steel. High carbon steel.
Light cherry red	800-900	
Cherry red	700-800	
Dull red	600-700	
First visible red	500-600	
<i>Oxide colours</i>		Springs Axes, screwdrivers Chisels, hacksaw blades General carpenters' tools Taps, dies, punches Drills, milling cutters Planing tools, scrapers } Tempering plain carbon tool steel.
Blue	300	
Purple	295	
Purple brown	285	
Brown	270	
Golden yellow	250	
Straw	240	
Pale yellow	200	

hot junction, protected by a porcelain tube, being located inside the furnace or bath.

108. When the open fire method of heating is employed, the temperature of the work is judged by its temperature colour, or, if the

ensure that it is clean; oil floating on the top of the water will gather on the part during immersion, and prevent cooling at the critical rate. Parts which are to be hardened throughout should be plunged straight into the quenching medium. If the part has to

be partially quenched, it is advisable to move it up and down to prevent the formation of a sharp hardening line which might subsequently be the cause of a crack. If the shape of the part is irregular, quench the larger portion first. When red-hot metal comes into contact with water, steam is formed which retards the rate of cooling; move the part rapidly in the water to lessen the adverse effect of the steam. Cracks or distortion during hardening or quenching are often due to internal stresses set up by previous forging, bending or machining; to avoid or reduce these stresses the part should be normalized prior to hardening.

Annealing

110. The temperature for annealing should be above the upper critical point for steels containing up to 0.87 per cent. carbon, and below this point for steels containing a higher percentage of carbon. For the annealing of single parts by the blacksmith's fire method, the job is heated to a cherry red. After heating, the part is allowed to cool slowly in hot ashes and excluded from draughts.

Normalizing

111. The temperature for normalizing will be the same as that for annealing the steel, but the rate of cooling is increased by allowing the steel to cool freely in the air. To remove the brittleness in cold-worked low-carbon steel fittings, they are sometimes heated to a temperature between 450°C. to 550°C., and allowed to cool as above; this treatment is referred to as low temperature normalizing.

Hardening and Tempering

112. **Hardening.** Steels containing 0.4 per cent. to 0.87 per cent. carbon, should be heated uniformly to a temperature about 30°C. above the upper critical point, and immediately quenched in water. With steels containing over 0.87 per cent. carbon, it is only necessary to heat to a temperature slightly above the lower critical point and quench, as at this temperature maximum hardness is obtained; a higher temperature would result in a coarse structure, the possibility of cracking, and some austenite may be retained. For the hardening of

small hand tools, such as chisels, punches, etc., the colour cherry red will correspond to the hardening temperature.

113. **Tempering.** Tempering at a temperature of 600°C. results in a structure with high strength, high elastic limit, good ductility and a high resistance to shock; this is used for certain alloy steels for engine parts. Tempering of a plain carbon tool steel is usually done at temperatures from 200°C. to 300°C., depending on the purpose of the tool. The higher the tempering temperature, the less the hardness but the greater the toughness of the tool. To temper, the steel is hardened in the normal manner, then reheated to the tempering temperature. The "one heat" method of hardening and tempering is applied to tools where the body of the tool is required to be soft and tough, and the point or edge hardened to the required degree.

114. **"One-Heat" Method of Hardening and Tempering.** The procedure for making a plain carbon steel chisel, and the "one-heat" method of hardening and tempering it are as follows:—

- (a) Heat the metal to a light cherry red, and forge to shape.
- (b) Normalize; when cold, grind roughly to shape.
- (c) Heat the cutting end half of the chisel to cherry red, then plunge it vertically into water to about a quarter of its length, moving it slightly up and down to prevent a sharp line between the quenched and unquenched parts, which would cause "waterline" cracks.
- (d) When the point is black, withdraw the chisel from the water; polish the point with emery or sandstone, and observe the temper colours forming on the polished surface as the heat flows down from the unquenched part of the tool.
- (e) When the desired colour (purplish-brown) appears, instantly quench the tip; wait, if necessary, till all visible red heat has died away before submerging the remainder of the tool.
- (f) Grind the cutting edge, taking care not to overheat this part during the operation.

Case-Hardening

115. The object of case-hardening is to give a low-carbon steel a high-carbon content on the surface, leaving the composition of the core of the metal unaffected by the process. The process consists of introducing extra carbon into the surface layers of the steel to be treated by heating it in contact with material rich in carbon, and finally applying the appropriate heat treatment. Various carburizing compounds are available and, in general, the case-hardening operation may be summarized as follows:—

- (a) Cementing or carburizing—to introduce the extra carbon.
- (b) Slow cooling from the cementing temperature—annealing.
- (c) Refining—to overcome the effects of prolonged heating.
- (d) Hardening.
- (e) Tempering as necessary.

116. **Open-Hearth Process.** This process is convenient for single parts if the depth of the hard case need not exceed 0.005 in. Heat the job to a light cherry-red colour and dip it in the carburizing compound; reheat and redip three or four times. Clean off any adhering compound, reheat and harden by quenching in water. Test the hardness by means of a smooth file, and finally polish the job with emery cloth. The maximum depth of hard case obtained by this method is approximately 0.005 in. Annealing and refining are not usually necessary.

117. **Box Process.** Clean the parts thoroughly and pack in an iron box (several parts may be put in the same box); each part should be surrounded by 1 to 2 in. of carburizing compound. Seal the lid with fireclay to prevent gas escaping during carburizing and to prevent the entry of furnace gases. Dry off the fireclay sealing, and place the box in the furnace; heat up to the carburizing temperature of 900°C., and maintain at this temperature for sufficient time to give the required thickness of case. As a guide, it may be taken that carburizing for 4 hours at this temperature gives a case approximately 0.040 in. thick; this is generally sufficient for ordinary jobs and allows a good limit for grinding. (Note that the depth of case is NOT proportional to the

time). Allow the part to cool down slowly in the box in order to anneal the newly formed case. Refine the part by heating to a temperature between 840°C. and 900°C., and quench in water or oil. Finally, harden the skin by heating the part to a temperature of 760°C. and allow to cool to 700°C. before quenching in water or oil.

Note.—Surfaces of the part not requiring case hardening treatment, can be protected by one of the following methods:—

- (a) A sufficient excess of metal on portions to be left soft is to be allowed to permit removal of the carburized layer prior to heat treatment.
- (b) The portions to remain unhardened are to be protected from carburization by means of an electrically deposited copper coating.

118. **Other Processes.** Other processes, which, although used extensively by manufacturers, are unlikely to be carried out by the tradesman, are the Cyanide Process and Nitriding. Brief details are as follows:—

(a) **Cyanide Hardening.** The job is immersed in molten sodium cyanide (920°C.), which provides both the necessary heat and the material for carburizing. This process is employed where a hardened layer of 0.008 in. to 0.010 in. is sufficient; articles carburized by this method may be directly hardened or subjected to the normal refining and hardening heat treatment.

(b) **Nitriding.** This is a process in which certain alloy steels assume an intensely hard surface when heated in an atmosphere rich in ammonia gas. These steels, generally known as nitriding steels, contain aluminium and chromium. The process consists of heating the parts in a box to a temperature of 500°C., and passing a steady stream of dry ammonia gas through the box for a period of from 10 to 90 hours; the thickness of the case produced ranges from 0.006 in. to 0.030 in. The relatively low temperature of the process and the elimination of quenching reduces the chances of distortion of the treated parts to a minimum.

HEAT TREATMENT OF NON-FERROUS METALS AND ALLOYS

Copper

119. Annealed copper is ductile and shock-resistant, but these qualities decline rapidly when the metal is cold-worked or is subjected to vibration—this is particularly noticeable in copper pipes, which rapidly harden and become embrittled when used in conditions of vibration. Ductility can be restored by annealing; this is done by heating the copper to dull redness (about 600°C.) and then quenching or allowing to cool freely in air. Where extensive cold-working is being performed, the copper may have to be reannealed several times before the work is completed. When using a brazing lamp to anneal copper, always try to keep the metal in the outer, non-luminous, cone of the flame when heating; exposure to the luminous tip of the flame tends to embrittle the metal instead of softening it.

Brasses

120. These alloys, like copper, respond best to cold-working processes when in the annealed condition, and the annealing treatment is identical with that for copper. The internal stresses set up by cold-working 70/30 or 63/37 brass may sometimes give rise to "season cracking", i.e., cracks which appear when the metal subsequently comes into contact with mildly corrosive agents, such as salt water or slightly acid atmosphere—these cracks appear quite suddenly, sometimes after years of service, and they may be extremely serious. Season cracking can be avoided by heating the brass, after cold-working is completed, to 280°C. and then quenching; this will relieve the internal stresses, but has little effect on hardness.

Aluminium Alloys

121. **General.** Aluminium is a weak but ductile metal. Its most important properties are its resistance to corrosion and its light weight, this being about one third the weight of iron. It is rarely used in the pure state owing to its low maximum strength. To increase its strength, it is alloyed with one or more elements such as copper, tin, nickel, manganese, magnesium, zinc or silicon. By subjecting the aluminium alloy to heat treatment or mechanical working, or by

varying the percentages of the alloying elements, various physical properties are obtained. Aluminium can take elements into solid solution at high temperatures, in the same way that carbon and other elements can be absorbed by steel. After quenching, however, the behaviour of some aluminium alloys is different from that of steel. On quenching steel, the solid solution is maintained at room temperature, but in aluminium alloys containing a high percentage of copper, the solid solution is not stable. The amount of copper that can normally be held in solid solution in aluminium is less than 0.5 per cent. at room temperature, and 4 to 5 per cent. at high temperatures, therefore, when the alloy is quenched from a high temperature, the excess copper commences to come out of solution. This action, termed precipitation, induces hardness (age-hardening) and strength, which is advantageous in the preparation of the alloy for certain purposes. Age-hardening takes place very slowly at room temperature, and may be suppressed by refrigeration. Some aluminium alloys harden so slowly that it is permissible to accelerate the process by low temperature heat treatment.

122. **Method of Heating.** A salt bath is usually used for the heat treatment of aluminium alloys. The salts, a mixture of potassium and sodium nitrates, are melted in a bath made of mild steel, and heated by gas, oil or electricity. Strict control of temperature is essential and each separate bath is provided with a thermometer. Heating must be carried out slowly; after the initial and subsequent heatings the salts solidify. If the heating of the solidified salts is done too quickly a volcanic failure of the crust will occur, attended by a shower of molten salt which is liable to cause a serious accident. Always ensure the bath lid is lowered during the heating period. When the salts are molten the bath should be three-quarters full. Having ensured that the material to be heat-treated is free from oil, grease or moisture, it is placed in a steel wire-mesh basket, or attached to wire, and suspended from rails across the bath so that it is totally immersed in the molten salts. To avoid local heat, i.e. that used to heat the bath, the material must not be in contact with the sides or bottom of the bath.

Note.—The same salts may be used indefinitely, but the bath should be cleaned out once a month by breaking up the salts and removing them, so that the sediment that may have collected at the bottom of the bath can be removed.

123. Period of Soaking. The time of immersion in the bath to ensure that the material is heated uniformly throughout, varies with the thickness of the job being treated. As a general guide, the material should remain in the salt bath for at least the following periods; an extra five minutes will not harm the material.

Material	Minutes
Sheet and strip	15
Rivets	15
Bars and thick sections	30
Heavy forgings	180

124. Cooling. After the necessary period of soaking, the material is removed from the bath and immediately quenched in water or oil, or allowed to cool in the air, depending on the specification of the material and the purpose of the heat treatment. As the salts are corrosive, it is advisable after cooling in the air to scrub the job in running water to remove all traces of salt. Care must be taken not to remove or damage the protective treatment, e.g. anodizing, which may have been previously given to the material.

125. Annealing. If considerable cold-working and forming has to be done to the material, it may be softened by annealing. The material is suspended in the salt bath, the temperature of which should be as specified; usually 360°C. to 400°C. After the period of soaking, the material may be quenched in clean, cold water, or allowed to cool in the air. The method of cooling annealed aluminium alloy does not normally influence the degree of softness, but when bending the material it will work-harden and may require to be annealed more than once before the bending operations are completed. Some aluminium alloys are very susceptible to corrosion when annealed, and should not be left in this state for long periods.

126. Normalizing. To secure maximum strength and hardness by age-hardening,

material which has been annealed must be fully solution heat treated (normalized). The alloy is maintained at a pre-determined temperature (ranging from 480°C. to 530°C. for different specifications of alloys), so that the constituents enter into solid solution. After the period of soaking, the material is quenched in water or oil, depending on the specification. In this condition the material is ductile, although slightly harder than when fully annealed, and simple bending or forming operations are permitted if completed within 2 hours after quenching.

127. Age-Hardening. Some aluminium alloys age-harden at room temperature, and attain their maximum strength within one to four days. Some require a second low temperature heat treatment at temperatures ranging from 100°C. to 200°C., for a period of 2 to 20 hours, to accelerate the process. Alloys of the latter class are not strictly age-hardening alloys, as this process is similar to the tempering of steel. The difference is that in steel, tempering reduces the hardness; in aluminium alloys, it increases the hardness. An explanation of temper-hardening of some aluminium alloys, is that the second heating at low temperature is necessary to make some of the dissolved constituents come out of solution to obtain maximum hardness of the material.

Notes.—

1. Normalizing must not be done in two operations; the whole job must be in the bath at once, otherwise part of the job may be permanently annealed.
2. Annealed aluminium alloy will not fully age-harden—all work must be normalized before going into service.
3. Heat treated aluminium alloy rivets, such as those made of duralumin, must be normalized before use, and not annealed.
4. Riveted parts must not be heat treated—salt may be trapped in the joint and cause corrosion, and the heat may cause permanent distortion. Normalize the material before riveting.
5. Annealed parts must not be riveted to normalized parts—owing to the difference in potential of electricity of annealed and normalized aluminium alloy, corrosion will occur.

6. The molten salts in a salt bath are dangerous—use great care to avoid burns from splashes of the salt. Any person receiving a burn from a splash of the molten salts must report for medical treatment immediately.

IDENTIFICATION OF METALS

General

128. Metallic material, when received into the Service, is marked in such a way as to indicate clearly the specification with which it complies and, where necessary, its condition, e.g., "Annealed", "Not Aged", etc. Identification markings are usually made with metal dies, but where such a procedure may have an undesirable effect upon the material, stencilling or printing with paint, enamel or ink is employed.

Standard Colour Code

129. The aforementioned markings may not be easily observed so an additional method, known as the Standard Colour Code, is employed to make identification more obvious. The appropriate identification colours for each specification are stated in A.P. 1086 and in A.P. 1464B. The colours are marked

in bands across corners of sheets and around the ends of tubes and rods. Should it be necessary to cut off material from a marked sheet, tube or rod, the cutting should be done in such a manner that the identification colours remain on the material which is not required for use.

Approximate Identification Tests

130. The approximate identification of some of the more commonly used metals may be established by making the tests shown in the following tables, but such tests must not be used as a substitute for the correct methods of identification when material to specification is required for use.

Note.—Alloy steels vary so much in composition that experience in their use is the only method of solving identification problems. For example:—

(a) The type of spark thrown when held against a grinding wheel is modified by the alloying elements.

(b) Austenitic steels and some stainless steels are non-magnetic.

(c) Copper is not deposited on stainless steel when copper sulphate solution is applied.

(i) Ferrous Metals.

Identification Tests	Grey Cast Iron	Wrought Iron	Mild Steel	High Carbon Steel	Tungsten Steel
Note when dropped on anvil.	No ring.	Low pitch ring.	Medium pitch ring.	High pitch ring.	Very high pitch ring.
Behaviour when chipped.	Chips break off from base metal before bending.	Very easily chipped. Chippings bend without breaking.	Easily chipped, Chippings bend without breaking.	Usually harder to chip than mild steel, Chippings bend without breaking.	Cannot be chipped.
Cooled in air from red heat.	Files easily, free carbon makes dirty deposit.	Soft, files easily	Soft, files easily	Can be filed, but tougher than mild steel.	Hard, cannot be filed.
Quenched in water from red heat.	No apparent change.	No apparent change.	No apparent change.	Hard and cannot be filed.	Hard and cannot be filed.
Appearance of fracture.	Dark grey crystals of uniform size.	Very coarse and fibrous.	Bright silvery, rather large crystals.	Pale grey, very fine crystals.	Silky - blue - grey. Very fine.
Types of sparks thrown when held against grinding wheel.	Dull red, non-bursting.	Bright yellow, non-bursting.	Bright yellow, few carbon bursts.	Bright yellow, all bursting.	Red, non-bursting, follow the wheel.

(ii) *Non-Ferrous Metals.*

Metal	Identification Tests
Aluminium	Tin white in colour, light in weight, non-magnetic; soft, and sheet aluminium bends easily. Application of caustic soda turns metal white; when anodically treated, an indelible pencil mark cannot be erased when rubbed with a moistened cloth.
Duralumin	Differs from sheet aluminium by being springy and more resistant to bending; application of caustic soda turns surface black.
Magnesium	Tin white in colour, very light, non-magnetic; easy to file, filings ignite in a flame; applications of copper sulphate causes effervescence and the affected parts turn black.
Solder	Tin white in colour, very heavy and soft; non-magnetic, low melting point (ascertained by use of hot soldering iron); will mark white paper due to lead content, cracking sound when bent indicates high tin content.

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