

MINISTRY OF SCIENCE AND TECHNOLOGY

**DEPARTMENT OF
TECHNICAL AND VOCATIONAL EDUCATION**

ME-01012

WORKSHOP TECHNOLOGY

A.G.T.I(First Year)

Mechanical Engineering

Content

Chapter	Title	Page No.
1	Engineering Materials	1 ~ 22
2	Foundry	23 ~ 32
3	Welding	33 ~ 71
4	Measuring Tools	72 ~ 83
5	Machine Tools	84 ~ 104
6	Benchwork	105 ~ 107
7	Buffing And Surface Finishing	108 ~ 116
8	Sheet Metal Work	117 ~ 123

CHAPTER (1) ENGINEERING MATERIALS

Commercial testing of materials

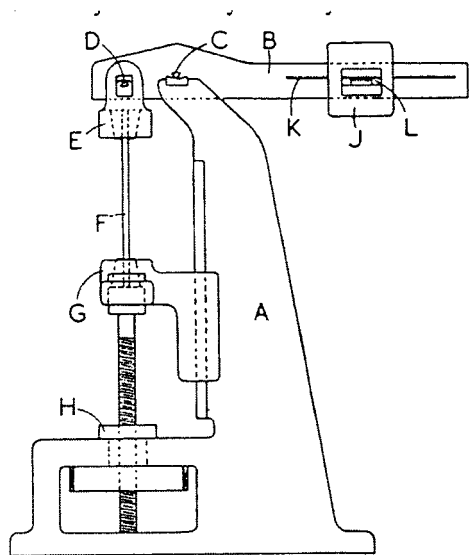


Fig. 1-1 Single lever testing machine

The Tensile Test

This is a very old-established test and is probably the most widely used of any. Briefly it consists in applying a tensile load, i.e. a pull, to a specimen of material and measuring the loads at which fracture occurs or at which the material ceases to be elastic, etc. The details of the machines in which these tests are carried out is no concern of this book, but a very brief consideration of their fundamental principles is desirable.

In Fig. 1-1 is shown a diagram of a single-lever testing machine. It consists of a column A, bolted to suitable foundations, on to of which a lever B is pivoted on a knife-edge C. A second knife-edge D supports the member E which is provided with means for gripping or holding the upper end of the specimen F that is being tested.

The lower end of the specimen is held in similar "grips" carried in the saddle G which can slide up and down the machined face of the column A (or which is otherwise guided) being actuated by various means; a screw passing through a rotatable nut H is shown, but hydraulic rams or other means are quite common. Free to slide along the lever or beam B is a "jockey-weight" J; by sliding this outwards (to the right) the pull applied to the specimen may be increased and the position of the jockey-weight provides a measure of the load applied to the specimen so long as the lever is "floating" and is not bearing against the stops provided to limit its motion to a reasonable amount. The lever is consequently furnished with a scale D that can read against an index or vernier L carried by the jockey-weight. Large testing machines are usually provided with a compound lever system and the specimen may be arranged to lie horizontally instead of vertically. Other load measuring methods than the lever and jockey-weight are also used.

Small extensions of the specimen, such as occurred while the material being tested remains elastic, can usually be accommodated by the tilting of the lever but any large extension must be taken up by lowering the saddle G; in many machines this can be performed by power.

In ordinary testing procedure the straining mechanism which operates the saddle G is set to work continuously at a constant rate and the jockey-weight is moved out along the lever to keep the lever balance; this requires some skill. Alternatively the jockey-weight can be moved out by regular steps and the lever be restored to the horizontal as necessary by operating the straining mechanism and lowering the saddle G. The rate of straining has been

shown to be generally unimportant in tests made at atmospheric temperatures, approximately the same results being obtained when the specimen is broken in a test occupying, say 15 minutes as in a test occupying only 1 minute. For some ductile materials and for tests at high temperatures the straining rate is important.

Bend Tests

These are carried out in order to verify that material is sufficiently tough and ductile; they are made by placing the bar to be tested on two supports at a specified center distance and then applying a load at the center of the bar by means of a round-ended strut or former. The bar is required to bend, without the appearance of any cracks, until the angle included between its straight portions reaches a specified value. The supports are sometimes rigid and sometimes take the form of rollers but their radii, as well as the radius of the end of the former, must have specified in relation to the dimensions of the test bar. For circular bars up to $\frac{3}{4}$ in. diameter and for rectangular bars up to $\frac{3}{4}$ in. width the test can be carried out in a simpler manner by means of a former and a vice; the bar and former are held in the vice and the bar is bent over the former is commonly made equal to twice the diameter or width of the bar. The bend test is much used for testing welds, as it shows up defects better than most other tests.

Impact Tests

A high value of the yield-point stress or of the ultimate strength is not always an indication that a material is suitable for withstanding the loads it may be subjected to in service. If the loads are applied suddenly, as blows, it will sometimes be found that a material giving very high values in the tensile test will fracture under much lighter blows than a material giving poorer tensile test results. To determine the suitability of a material under these impact conditions various forms of impact test have been evolved. Only two are of any great importance, namely, the Izod and the Charpy, and in Great Britain only the Izod is at all widely used.

The Izod Test

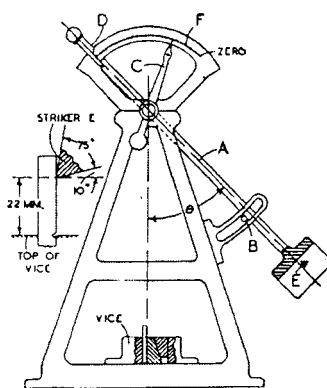


Fig 1-2

The specimen is commonly shaped as being designed so that four tests can be made on each specimen. The latter is held in the vice of the testing machine as indicated in Fig. 1-2, the center of the notch being set level with the vice jaw by means of a simple gauge. The pendulum A of the machine is then released from the catch B, on which it has previously been placed, and swings over so that the striker E hits the specimen, as shown in the inset sketch, and fractures it. Since it requires energy to fracture the specimen the pendulum will swing past the vertical to some angle θ_1 that is smaller than the angle θ from which it started at the other side. The difference $\theta - \theta_1$ is a

measure of the energy expended in fracturing the specimen and can be read off the scale F against the idle pointer C. The latter is moved across against a projecting pin of the pointer D at the beginning of the test and remains in the position to which it is pushed as the pendulum swings over. The potential energy of the pendulum when it rests on the catch B is 120 ft.-lb. The zero of the scale lies at the point reached by the pointer D when the pendulum is released without there being a specimen in the vice.

The Charpy Test

This is similar to the Izod in general principle, but the specimen is mounted as a beam as shown in Fig. 7 instead of as a cantilever. The specimen is 10 mm square in section as for the Izod test and the Izod form of notch is sometimes used. The striker of the pendulum is also arranged so that it is approximately coincident with the center of percussion of the pendulum.

The British Standard shapes and dimensions for Izod and Charpy specimens are laid down in B.S. 131:1933.

The results obtained for a given material in either the Izod or the Charpy test will only be comparable when the specimens used are identical in size, shape of notch, etc., and it is therefore important that standard specimens should be used.

Hardness Tests

Numerous methods and machines for testing the hardness of materials have been tried but only in few are in extensive in use, namely, the *Brinell*, *Vickers diamond* (V.D.H), *Rockwell*, and *Shore scleroscope*.

The Brinell Test

This is one of the oldest and also one of the most widely used hardness tests and consists of pressing a hard steel ball, usually 10 mm in diameter, into the specimen by applying a standard load, usually 3,000 kg., thereby producing a depression in the specimen. The diameter of this impression is measured by means of a specially graduated microscope and the Brinell hardness number may then be calculated from the equation,

$$\begin{aligned} \text{Brinell Number} &= \frac{\text{Applied Load (kg)}}{\text{Spherical area of the impression (sq. mm)}} \\ &= \frac{P}{1.571D \left(D - \sqrt{D^2 - d^2} \right)} \end{aligned}$$

where D = Diameter of ball

d = Diameter of impression

P = Applied load

Usually, however, the hardness number is looked up against the appropriate value of *d* in tables.

It has been shown that provided the load is made proportional to the square of the ball diameter the impressions produced will give a constant hardness number on a given specimen. In practice the standard 10 mm ball and 3,000 kg load are departed from only for tests on thin sheets and soft material; the British Standard Specification dealing with the Brinell test (No. 240: Pt. 1:1937) provides for a number of different sizes of ball and gives the corresponding appropriate loads. For very hard materials, which would give a Brinell number greater than about 500-600 a tungsten-carbide, ball has to be used, because the deformation of a steel ball becomes sufficient to affect the results appreciably.

Special machines, some of them power operated, have been developed for making the Brinell test, which is widely used in engineering works as an acceptance test for discriminating between satisfactory and unsatisfactory material.

The Vickers Diamond Test

This also consists of pressing an indenter into the specimen by means of a standard load. The indenter is, however, a diamond pyramid (and the hardness given by the test is sometimes referred to as the D.P. hardness) and has a square base and a facet angle of 136 degrees. It makes a square pyramidal impression in the specimen and the diagonals of this impression are measured with a microscope, which is usually part of the machine used; the mean value of the readings gives the hardness number from the equation,

$$\begin{aligned} \text{V.D.H or } H_D &= \frac{\text{Load}}{\text{Surface area of impression}} \\ &= \frac{2P \sin \theta/2}{d^2} \end{aligned}$$

Where, P=load in kg., d=mean diagonal in mm., and θ =angle of the diamond pyramid. The British Standard loads (see B.X. 427:1931) are 5, 10, 20, 30, 50, 100 and 120 kg. The load used should be stated, thus $H_D 50=x$, $H_D 20=y$. New forms of diamond indenter have been developed recently for testing brittle materials and very thin sheets.

The Firth "*Hardometer*" uses a pyramidal diamond just like that used in the Vickers machine and measures the width across the resulting impression so that it gives the same hardness numbers as the Vickers.

The Rockwell Test

This also consists in pressing a diamond indenter into the specimen under a standard load, but the diamond is conical with a rounded point and the *depth* of the impression is measured while the load is on, and is used to give the hardness number. In order to eliminate the effects of backlash and spring in the machine and its integral measuring instrument a small or *minor* load of 10 kg is first applied and the measuring instrument is set to zero, then a large or *major* load is applied and the hardness number is read off the instrument. The major load used with the diamond indenter is generally 150 kg and the corresponding hardness number is referred to as "Rockwell C" A 1/16 in diameter ball is also used as an alternative indenter with a major load of 100 kg and a separate scale is provided on the measuring instrument for use with it. The corresponding hardness is referred to as "Rockwell B". Other indenters and major loads are sometimes used; the corresponding

hardness numbers being designated by other letters, and it is important that the proper letter applying to the particular indenter and major load used should be quoted.

In the *Monotron* hardness test, which is used to some extent in America, a $\frac{3}{4}$ mm diameter diamond ball is caused to penetrate the specimen to a constant depth of 0.045 mm and the *load* required to produce this penetration is used to give the hardness number by dividing it by the spherical area of the impression. Thus in this test and in the Rockwell, as opposed to the Brinell, Vickers, and Firth tests, the elastic deformation under the applied load is taken into account in arriving at the hardness number.

Ductility Tests

In press-tool work the ductility of the material is a most important factor and many attempts have been made to devise a test which will give a reliable indication of the suitability or unsuitability of material for drawing operations in press-tools. The only test that is at all widely used, however, is the *Erichson cupping test*. This carried out in a standard form of machine, the test piece A (Fig. 1-3) being gripped between the holder B and die C. After the holder has been tightened on to the specimen it is slacked back a constant amount (0.05 mm) to give the specimen freedom to draw and the cupping tool D is then pressed into the specimen until cracks appear on the dome of the cup, these being observed in the mirror E. The depth of cup at fracture is read off the scale of the machine and is a measure of the drawing quality of the material. Fig. 1-4 shows Erichson's standard curves giving the depth of cup for various thickness of sheet and kinds of material.

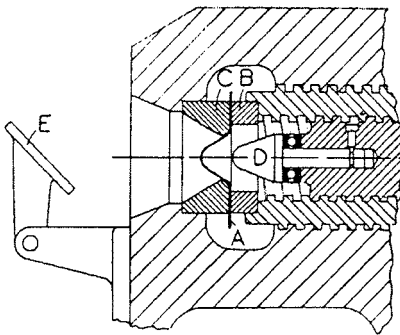


Fig 1-3

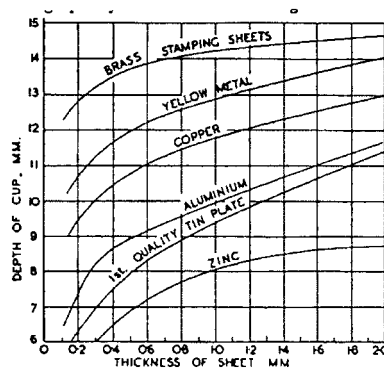


Fig. 1-4

Fatigue Testing

It has been known for nearly a century that a bar of metal that is subjected to a load which is applied and removed a large number of times, or which fluctuates between two limiting values, can be fractured despite the fact that the maximum value of this load may be considerably less than the value corresponding to the elastic limit in an ordinary tensile test. This phenomenon has come to be denoted by the term "fatigue".

Three conditions of loading may be distinguished and are called respectively *fluctuating*, *repeated*, and *alternating* or *reversed* loads. The fluctuating load may vary between two positive limits as shown, when it may be called a *pulsating load*, or between a

positive and a negative limit. The repeated and alternating loads are merely special cases of the fluctuating load.

Considering the alternating type of loading, if a large number of tests are made on a corresponding large number of specimens in which the range of load $2P$ is gradually reduced and if the number of reversals necessary to produce fracture are plotted against the range of stress. This implies that fracture will never occur provided that the range of stress is kept within some value t , but, of course, from the nature of the test, it is not possible to say whether this is actually so or not. In practice the limiting range of stress that will not produce fracture in 10,000,000 reversals is generally taken as the fatigue strength of a material. The results depend on the type of machine used to some extent, but similar types of machine give similar results.

Numerous machines have been developed to test fatigue strengths but only two types are of sufficient importance to be described here; they are the Wohler and the Haigh machines.

Elementary properties of ferrous and non-ferrous metals

Pig Iron

Pig iron is weak and brittle and is not used for structural purposes. Ordinarily, it is poured into large ladles and taken to a cupola or to an air furnace for making cast iron, or to the refining furnaces for making steel. If it cannot be used immediately, it is cast into blocks or pigs, which may be remelted later. The different ores and various blast-furnace procedures produce many grades of pig iron, each one with a special use in the foundry or the steel mill.

Cast Iron

Cast iron is used in industry because of its low cost, good casting characteristics, high compressive strength; wear resistance, and good damping qualities. The principal types are: gray, white, malleable, ductile (nodular), and various alloy irons.

When cast iron solidifies, the last liquid to freeze is of the eutectic composition. If no other alloying element is present, the quantity of carbon must be at least 1.7 per cent for the eutectic transformation to occur. If the percentage is lower, there will be no final solidification of eutectic liquid, and the solid will not be cast iron. Impurities and alloys, however, change this value considerably; for instance, 2 per cent silicon lowers the possible carbon limit from 1.7 to 1.1 per cent.

Gray Cast Iron

Twelve to 15 million tons of cast iron are produced in the United States each year. Of this total, gray cast iron comprises 85 per cent. It is made from low quality foundry pig, which is charged (along with scrapped castings and coke) into a cupola. The cupola is similar to a small blast furnace, and is the best place to melt scrapped castings, therefore salvaged cast scrap is used to control the alloying elements in the finished cast iron.

White, or Chilled, Cast Iron

White iron has a characteristic white color because it contains no graphite. All of the carbon is in the form of cementite, either free or in lamellar pearlite (see Fig. 1-5). White iron

may be produced by two methods: (a) by casting gray iron against chills to cool it rapidly and give it a white surface layer, or (b) by adjustment of composition through keeping carbon and silicon low so there is no free carbon throughout.

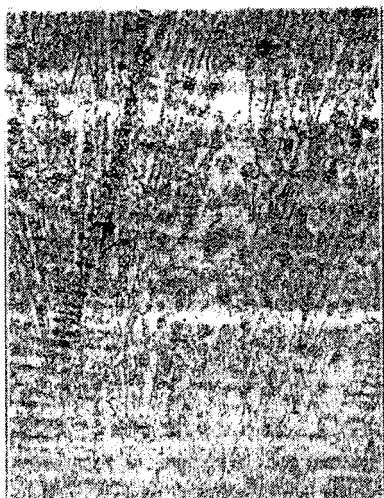


Fig.1-5 Photomicrograph of white cast iron x 250

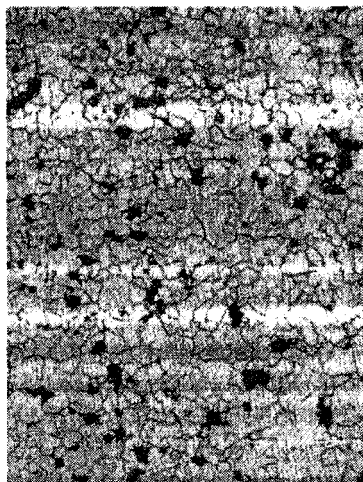


Fig.1-6 Photomicrograph of malleable cast iron x 125

Malleable Cast Iron

Approximately 1 million tons of the white iron casting made in the United States are converted into malleable iron castings each year. This is done by annealing to dissociate the cementite. In Europe, the castings are packed in an oxidizing material, and the malleablized castings are known as “white heart,” through removal of some carbon. The practice in the United States is to anneal castings packed in an inert material, such as ferrous silicate scale or slag. These malleablized castings, known as “black heart,” consist almost entirely of graphite and ferrite. The carbon, previously in the form of cementite (Fig: 1.5), agglomerates and forms “rosettes” of pure temper carbon scattered in a matrix of almost pure iron (Fig: 1-6). The annealing process consists in heating slowly to 1600 F, holding at temperature for 25 to 60 hr, depending on size, and slow cooling at 10 F per hr.

Ductile Cast Iron

A development of importance to the foundry field has been the successful production of ductile iron. Small additions of magnesium (or more expensive cerium) at the ladle renders the graphite content nodular, or spheroidal, in form, and well dispersed throughout the material. The resulting structure possesses properties more like a cast steel than like the other grades of cast iron, yet production follows gray-iron practice.

Ductile iron is not a single material, but is, instead, a family of materials. Its structure may be modified by alloys or heat treatment, as in steel, to produce austenitic, acicular, martensitic, pearlitic, and ferritic structures.

Alloyed Cast Iron

Many foundries have attempted unsuccessfully to produce alloyed cast irons in cupola furnaces, but the difficulties met in attempting to add alloying elements in the cupla are almost insurmountable. The alloying compounds may be added to the cupola charge, but very often do not melt evenly. The castings then have nonuniform composition. If the alloys are added to the poruing ladle after the molten iron is drawn from the furnace, the ladle iron must be very hot to overcome the chilling effect of the alloy, and even then the mixture is apt to be nonuniform.

Many of the disadvantages of the cupola are overcome by use of the "batch process" in an air furnace or an electric furnace. In these furnaces it is possible to control the composition, since the charge is melted all at once, instead of continuously as in he cupla. Probably about 15 to 20 per cent of eh cast iron being produced now is alloyed, and many foundries make a specialty of this type of casting.

Table 1-1 Properties Typical of Some Alloy Gray Cast Iron

Property	ASTM Class					
	30	35	40		50	60
Tensile strength, psi	30,000	35,000	40,000	45,000	50,000	60,000
Compressive strength, psi	100,000	110,000	125,000	135,000	150,000	175,000
Hardness (Brinell)	170	190	210	230	250	275
Permanent set, psi	9,000	11,000	13,000	15,000	17,000	19,000
Endurance limit, psi	15,000	17,000	20,000	22,000	25,000	30,000
Mod. of elasticity, psi	14,000,000	15,000,000	16,000,000	17,000,000	18,000,000	20,000,000
Torsion modulus, psi	5,500,000	6,000,000	6,500,000	7,000,000	8,000,000	9,000,000
Toughness (Izod impact)	Less than 1	..	Up to 2	Up to 2
Creep, 0.1% 1000 hr						
840 F	..	9500				
1000 F	..	0				
Machinability	Excellent	Excellent	Excellent	Excellent	Good to exc.	Good to exc.
Wear resistance	Excellent	Excellent	Excellent	Excellent	Good to exc.	Good to exc.
Corrosion resistance	Fair to good	Fair to good	Fair to good	Fair to good	Fair to good	Fair to good
Vibration damping capacity	Excellent	Excellent	Excellent	Excellent	Good to exc.	Good to exc.
Specific gravity	7.1	7.1	7.2	7.2	7.3	7.3
Melting point, F			2150-2300			
Thermal exp. $\times 10^{-6}$ F	6.7	6.7	6.7	6.7	6.7	6.7
Thermal conductivity, cgs units	0.11	0.12	0.12	0.12	0.12	0.12
Electrical res., microhm-cm	80-100	80-100	80-100	80-100	80-100	80-100
Magnetic permeability, gaussess with H at 100	9000	9000	9000	10,000	10,000	10,000

The principal reasons for alloying cast iron are to increase its strength and to improve its corrosion resistance. Since alloying is a process requiring special melting practice, alloys are added to good irons to make them better, never to poor irons to make them good.

Nickel in amounts up to 5 per cent is added to cast iron primarily for its effect on machinability; it may be made either to increase the hardness and strength without appreciably decreasing the machinability, or to improve machinability without decreasing the hardness and strength. The nickel also promotes corrosion resistance and uniformity of properties throughout variations in casting thickness.

Chromium, up to 3 per cent, has the opposite effect of silicon and nickel; it inhibits the formation of graphite, promotes the formation of carbides, and, in addition, increases the corrosion resistance. Higher percentages of chromium therefore harden the iron by increasing the percentage of combined carbon.

Nickel and chromium added in 3-to-1 ratio to 4 per cent total have their graphite- and carbide-forming tendencies neutralize each other, and this results in iron with improved grain refinement, hardness, and strength, and with no impairment of the machinability.

Molybdenum, up to 1.5 per cent, is the most effective alloying element for improving strength; wear resistance is also increased, with a consequent decrease in machinability. Molybdenum improves the uniformity of structure in heavy sections by slowing up graphitization and retarding the critical transformation.

Vanadium, up to 0.5 per cent, is a very powerful carbide former and increases the strength and hardness of cast iron considerably, even in the small amount used.

Properties typical of some alloy gray irons are listed in Table 1-1. The lower grades are used for such parts as cylinders, brake drums, and sprockets. Higher grades are used where high impact, wear, and fatigue resistance are required as in dies, machine-tool castings, and critical machinery components.

Austenitic Gray Cast Iron. If iron is alloyed in such a way that the critical transformation temperature is lowered below room temperature, the iron will remain in the form of austenite (γ -iron) rather than transforming to ferrite (α -iron) as it cools to room temperature.

Austenitic cast iron, which bears the same relationship to ferritic cast iron that stainless steel bears to carbon steel, has excellent corrosion and erosion resistance and good wearing qualities, strength, and hardness.

Nickel, 10 to 20 per cent, is the only alloying element known that alone causes its carbide content to increase. Martensitic nickel irons are also available.

Inoculated Irons. High-strength irons of such composition that they would ordinarily be white as cast are often inoculated in the ladle with a silicon compound to cause graphitization. Typical agents used are ferrosilicon, calcium silicide, Si-Mn-Zr, or Ca-Mn-Si in crushed form. Trade names are used to designate the inoculated products, and the practice may be employed with plain carbon or alloy cast irons. The resulting product is a uniformly dense and machinable casting which might have been "white" in thin sections and soft and porous in heavy sections.

Non-Ferrous Metals Alloys

The non-ferrous materials used in engineering are nearly all alloys, the chief exceptions being copper, aluminium, and nickel which are used fairly extensively in the unalloyed state. Non-ferrous alloys are very numerous; they may be grouped thus:

1. Brasses- alloys of copper and zinc.
2. Bronzes- alloys of copper and tin.
3. Special brasses and bronzes.
4. Copper-nickel alloys.
5. Nickel alloys.
6. Bearing alloys.
7. Aluminium alloys.
8. Magnesium alloys.
9. Miscellaneous alloys.

Copper

Three principal types of copper are used in engineering, namely, high conductivity (H.C) copper, best select copper, and arsenical copper. The three varieties normally contain a small percentage of oxygen and are then known as “tough-pitch,” but “de-oxidised” and “oxygen-free” coppers can be obtained and thermal conductivities obtainable in the metal; best select copper contains small conductivities various impurities, but is suitable for most purposes; arsenical copper contains up to about 0.5 per cent of arsenic, which improves the mechanical properties but greatly reduces the electrical conductivity.

Copper can be, and is, cast, but its mechanical properties are greatly improved by rolling, forging, etc., and it is readily worked at temperatures of 800°-900° C. It is used chiefly in the cold-rolled and annealed state. The amount of cold-working determines the “temper” of the copper which may be “soft” (V.D.N. under 60), “half-hard” (V.D.N. 70-90) or “hard” (V.D.N. over 90). Typical values for the mechanical properties are given in the table below:

Condition	Ultimate strength Tons per sq. in.	Elongation on 2 in. Per cent	Brinell no.
As cast	10-11	25-30	40-45
*Cold-worked	20-26	5-20	80-100
*Cold-worked and annealed	14-16	50-60	45-55

- These figures apply to sections exceeding $\frac{1}{8}$ in. in thickness.

When heavily worked, as, for example, in wires, the tensile strength may be as high as 30 tons per sq. in., the elongation being then only 1-5 per cent.

Special Copper

Small additions of various metals have important effects on copper, the addition of only 0.1 per cent of silver raises the annealing temperature of copper to 300°-350° C. and enables the hardened condition to be maintained after tinning operations that would soften

ordinary copper. Between 0.6 and 1 per cent of cadmium decreasing the conductivity. Tellurium improves the machining properties. Coppers containing 2 per cent of beryllium have ultimate strength of 60-80 tons per sq. in. and are used for springs, diaphragms, and bellows in instruments; they may be annealed by quenching from 800° C. and hardened by heating to 300-320° C. Similar properties are obtained by the addition of 2.6 per cent of cobalt and only 0.4 per cent of beryllium.

Brasses

These may be subdivided into

- (a) the α -brasses, containing up to about 37 per cent zinc;
- (b) the α - β brasses, containing between 40 and 44 per cent zinc.

The α -brasses are capable of being cold-worked to a remarkable extent, and may be rolled, pressed, and drawn. They can also be worked hot, but not nearly so readily as cold, while the presence of quite small amounts (0.1 per cent) of impurities such as lead will make them "hot-shot." Two "qualities" of brass are commonly used, basis quality, containing about 63 per cent copper and 37 per cent zinc, and cartridge brass, containing about 70 per cent copper and 30 per cent zinc. A variation of latter is Admiralty brass, whose composition is 70 per cent copper, 29 per cent zinc, and 1 per cent tin. In the annealed state cartridge brass has an ultimate strength of about 20 tons per sq. in., an elongation of about 70 per cent on 2 in., and a Brinell hardness of about 60. Cold-working hardens the α -brasses and reduces their ductility; thus, hard-rolled sheet gives an ultimate strength of about 35 tons per sq. in., and elongation of about 12 per cent, and a Brinell hardness of between 150 and 200. Four "tempers" are commonly recognized as being imparted to brasses by various amounts of cold-working; they are: (1) Soft; (2) Quarter to half-hard; (3) Hard; (4) Extra or spring hard.

The annealing of brasses is a re-crystallisation process, during which new small crystals are formed. This re-crystallisation does not occur at temperatures below 280° C., and heating to within this limit is done merely as a stress-relieving operation. At temperature over 400° C. grain growth may occur if the heating is unduly prolonged. Annealing is usually done at temperature between 300° and 600° C., and the material may be quenched in water, or cooled in air, afterwards the rate of cooling being unimportant.

Articles made of α -brasses that have cold-worked often exhibit what is called season-cracking—the formation of cracks some time after manufacture and without the application of any external load. This is due to the internal stresses left in the material by the cold-working, and is accelerated by corrosive atmospheric conditions. It can be obviated by stress-relieving the articles by heating them to between 250° and 275° C. for half an hour to one hour. As mentioned above, this treatment has no effect on the mechanical properties of the brasses.

Brasses do not show any well-marked yield point or elastic limit, and so it is common practice to specify a proof stress.

Gilding Metals

These are copper-zinc alloys containing 80-95 per cent of copper and they are used chiefly for decorative purpose although they do have engineering uses.

Bronzes

These are alloys of copper and tin; although up to 16 per cent of tin may be retained in solution in copper if the alloy is cooled very slowly, the amount that can be retained with practical rates of cooling is about 8 per cent. Bronzes containing up to 8 per cent of tin correspond, therefore, roughly to the α -brasses; they can be cold-worked, but not so easily as the brasses. Tin contents greater than 8 per cent are used for casting and small amounts of phosphorus are sometimes added to help in the elimination of tin oxide and to improve the mechanical properties. Excess of phosphorus leads to brittleness and normally the content is only about 0.05 per cent; in true phosphorbronze the phosphorus content is from 0.1 to 1.0 per cent. In the form of castings phosphor bronze will give an ultimate strength of about 18 tons per sq. in. with an elongation of about 4 per cent. The wrought bronzes will give ultimate strengths of 22-24 tons per sq. in. with elongation of about 60 per cent in the annealed state, while in the worked condition the ultimate strength may be as high as 50-60 tons per sq. in.

Gun Metal

This is an alloy of copper, tin, and zinc and is widely used for castings, particularly when they are of complicated form. A common composition is copper 88, tin 10, and zinc 2 per cent, and this will give an ultimate strength of about 17 tons per sq. in. together with an elongation of about 20 per cent. The zinc content may be as high as 6 per cent.

Special Brasses and Bronzes

Additions of manganese, nickel, iron, aluminium, and some other elements improve the properties of brass and bronze and are widely used. In brasses the resulting materials are generally known as high tensile brasses, but the name bronze is often misapplied. An example of a high tensile brass is delta metal, which is an α - β -brass containing about 2 per cent of iron and 1 per cent of manganese; this alloy may be cast, may be worked hot (above 500° C.), is resistant to corrosion, and has mechanical properties that make it a useful substitute for mild steel. Another example is manganese bronze; this is an α - β -brass plus 1-2 per cent of manganese and, sometimes, 2-3 per cent of nickel and up to 4 per cent of aluminium. Tensile strengths from 30 to 35 tons per sq. in., together with elongation of 10-35 per cent, can be obtained and the properties can sometimes be improved by heat treatment. Manganese bronzes can be forged and hot stamped between 600° and 750° C. but are hot short at higher temperature; they are subject to undue grain growth if held for too long between 700° and 800° C. and the mechanical properties are then greatly reduced; this cannot be remedied except by re-melting.

In recent years much progress has been made in the development of brasses that can be heat treated so as to be made soft for working and then hardened and improved in mechanical properties. One such alloy has the composition, copper 72 per cent, nickel 6 per cent, quenching in water from 850° C. and hardened by re-heating to about 500° C. and cooling slowly. Its properties are shown in the table on top of the opposite page.

Condition	Ultimate strength Tons per sq. in.	Proof stress Tons per sq. in.	Elongation Per cent
Annealed	23	5	60
Heat treated	36	22	30
Heat treated after cold working	48	45	11

The aluminium content also improves the corrosion resistance.

Aluminium Bronzes

This name has been given to alloys of copper with up to 12 per cent of aluminium and, sometimes, nickel, manganese, and iron. The copper-aluminium alloys containing less than about 7 per cent of aluminium are known as alpha aluminium bronzes and possess valuable cold-working properties; for example, an alloy containing 4 per cent of aluminium will give an elongation of 80 per cent on 2 in.; these alloys may consequently be readily worked cold. Alloys containing from 8 to 12 per cent of aluminium are of duplex structure and may be worked at all temperatures up to about 950° C. by rolling, forging, extruding, etc. Alloys containing 9-10 per cent of aluminium are used for castings and will give a tensile strength of about 30 tons per sq. in. and an elongation of 20-40 per cent some 30 per cent higher. The duplex alloys can be improved by quenching from relatively high temperatures (900° C.) followed by tempering at from 400-650° C. for periods of about 1 hour.

Nickel Bronzes

These are of two types: (a) low nickel, and (b) high nickel. The former contain 3-5 per cent of nickel, 5-10 per cent of tin, and 0-2 per cent of zinc, and in the form of sand-mould castings will give an ultimate strength of 18-24 tons per sq. in. with an elongation of 20-10 per cent. The high nickel bronzes contain 15-60 per cent nickel, 6-12 per cent tin, 1-2 per cent zinc, up to 3 per cent silicon, and 0.1 per cent magnesium. They will give, in the sand-cast state, ultimate strengths up to 30 tons per sq. in.

The Heat Treatment of Steels

Broadly speaking this phrase covers the processes by which the required structures, and consequent physical properties, are obtained in the steel by heating it to suitable temperatures and then cooling it at suitable rates. The chief treatments are:

1. Annealing
2. Normalizing
3. Hardening
4. Tempering
5. Stress relieving
6. Carburising, nitriding, and other processes for producing surface hardness.

Annealing

This consists in slowly heating the steel to a temperature somewhat above that defined by the line EGK in Fig.1-7, for the given carbon content, and then letting it cool down in the furnace or at a very slow rate. The objects sought are threefold: first, to relieve any internal stresses remaining in the metal as the result of previous treatment; secondly, to soften the steel by producing a pearlitic structure; and thirdly, to bring the steel to a condition suitable for subsequent heat treatment.

V

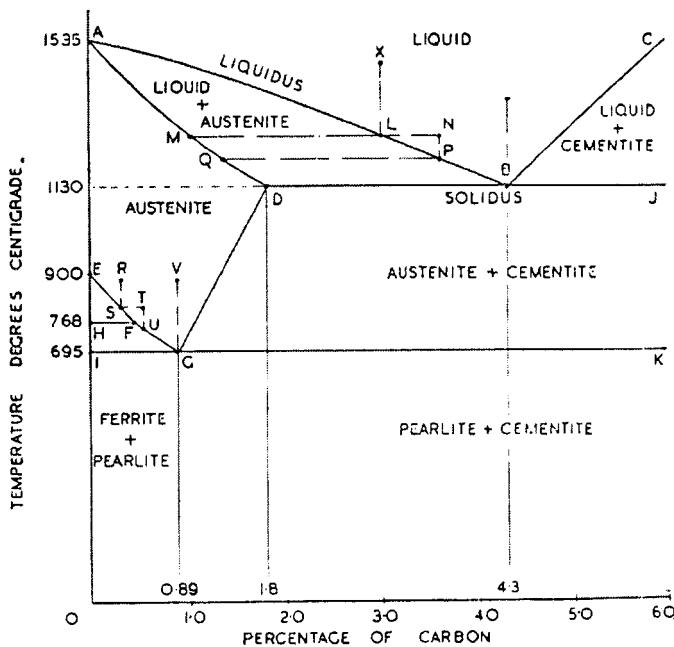


Fig.1-7 Equilibrium diagram

Normalizing

This is done by heating the steel to temperatures somewhat above those defined by the line EGD (Fig.1-7) and letting it cool in air. It produces a homogeneous structure

consisting either of finely laminated pearlite or sorbite; it also reduces the size of the crystal grains which may have been increased by prolonged heating during earlier processes. Normalized steel is usually stronger and harder and may be more machinable than an annealed steel.

Hardening

This is done by heating the steel to temperatures equal to those used, for the same carbon content, in annealing and then quenching it in water or oil or, sometimes, in other substances. Usually a martensitic structure is desired as the result of hardening and with plain carbon steels this requires very rapid cooling. The addition of certain elements enables the cooling rate to be much lower and this is one of the most important advantages of the alloy steels, the less drastic quenching required obviating distortion and cracking difficulties.

Tempering

This consists of heating a hardened steel to a temperature somewhere between atmospheric and about 695° C and, with some alloy steels, then cooling it fairly rapidly by quenching in water, oil or other fluid. The process relieves the severe internal stresses produced by the hardening process and partly breaks down the martensitic structure thus making the steel less brittle though softer. Untempered hardened steel will scratch glass but is exceedingly brittle; as the temperature at which the steel is subsequently tempered is raised, the steel becomes softer but tougher.

Stress Relieving

In this treatment articles are heated to temperatures, which while high enough to enable internal stresses set up by previous processes, either mechanical or thermal, to be relieved, are not high enough to produce any change in the structure of the material.

Isothermal Transformation Diagrams

These show the time taken by steel to transform, at a constant temperature, from austenite to other structural forms. They can be derived only as the result of numerous experiments of the following nature. A sample of the steel is heated to a temperature at which it will be entirely austenitic and is then quenched to a lower temperature at which it is held for a measured time after which it is quenched to room temperature; the extent to which the transformation has proceeded is then determined by microscopic examination or by other methods. In this way the diagrams, an example of which is shown in Fig. 1-8, may be built up. The diagram consists of two main boundary lines XXX and YYY; the former showing the commencement of transformation and the latter the completion of it. Thus if the temperature to which the sample is quenched and at which it is held is say 650° C then in the example shown it will take about 9 minutes for transformation to commence as indicated by point X₁; this period is called the *incubation period*. The transformation, to a mixture of

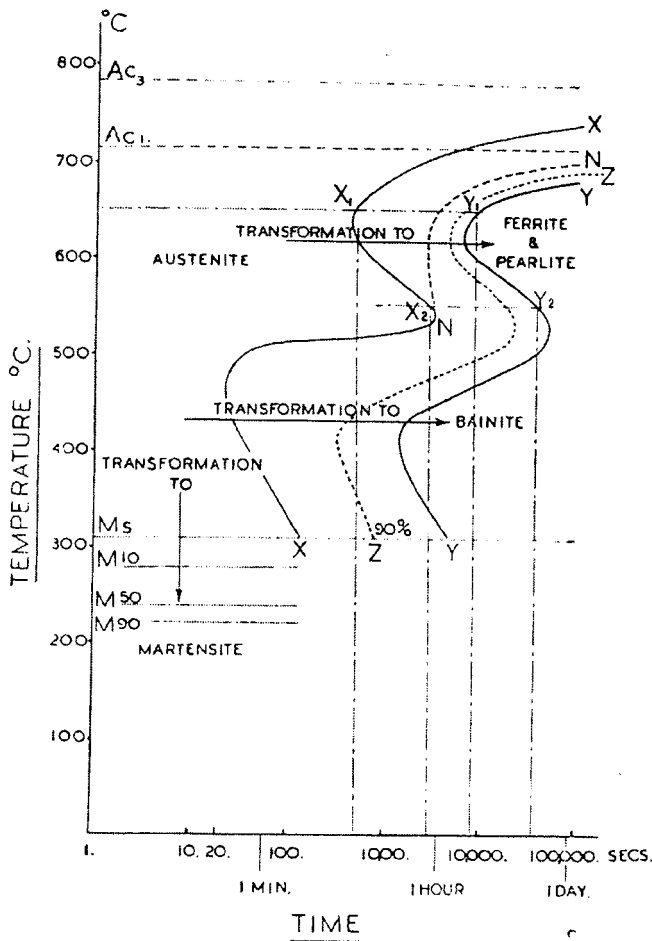


Fig 1-8 Isothermal transformation diagram

at which the incubation period is a minimum, that is the point X_1 , approximately, is called the *knee* of the curve.

If the temperature of the austenitised sample is lowered sufficiently rapidly to avoid transformation to bainite (in the example this would require the temperature to fall to that shown by the line M_s in less than about 20 minutes) then at the M_s temperature some of the austenite will be transformed to martensite but the amount will be small. If the temperature is not further reduced, then no more martensite will be produced, but as the temperature is lowered so more and more martensite will be formed until at room temperatures all the austenite will have been transformed into martensite. The lines M_{10} , M_{50} and M_{90} indicate the temperatures at which approximately 10, 50, and 90 percent, respectively, of the austenite will have been changed into martensite. However, in some steels austenite may be retained at room temperatures and in some the (M_f) temperature at which all of the austenite will have been changed into martensite is well below zero.

The hardness of a fully transformed martensitic structure is determined by the carbon content and is influenced only slightly by other alloying elements, but any retained austenite will reduce the hardness. Hardened and tempered steels develop their best combinations of

ferrite and pearlite, will be complete, as indicated by the point Y_1 in about 2 ½ hours. At a holding temperature of 550° C. The transformation to ferrite and pearlite occurs, in some steels, in two stages and the line NN indicates the boundary between these stages; it is sometimes called *carbide line*. If the holding time at any particular temperature is less than that required for complete transformation to occur then on final quenching the unchanged austenite will be transformed into martensite and the structure will be a mixture of ferrite, pearlite, and martensite; as indicated above it is from the estimation of the amount of martensite in the structure that the extent to which transformation was complete at final quenching is judged. Intermediate lines such as ZZ may be drawn to indicate the percentage of martensite. Below a temperature of about 550°C in the example the transformation when completed will not be to ferrite and pearlite but to an intermediate structure which is referred to as *bainite*. The point of the curve XX

tensile strength, ductility, and impact strength when their structures consist wholly of tempered martensite and the presence of ferrite, pearlite, or bainite will usually reduce the proof stress, impact and fatigue strengths and, in some cases, the elongation and reduction of area associated with a given tensile strength.

The general effect of carbon and of the most usual alloying elements is to move the isothermal transformation curves to the right; they also tend to make the "nose" (N in Fig. 1-8) more prominent so that it may not appear on the diagram unless the time scale reaches several days. Some elements have only small effects on the incubation periods but make large changes in the transformation rates while other elements do the opposite. Some examples of isothermal transformation curves are sketched in Fig. 1-9.

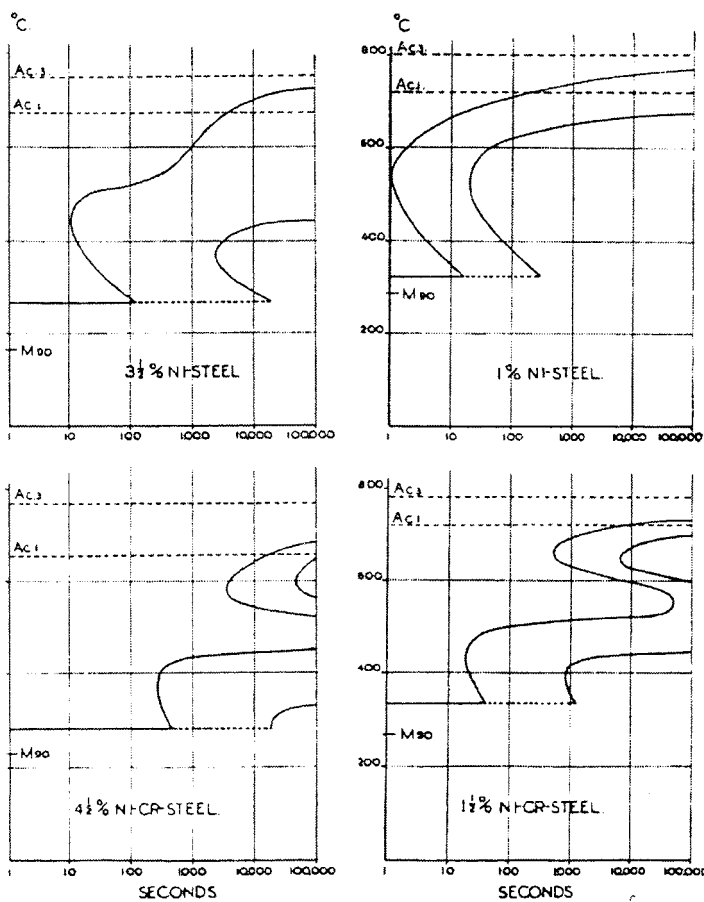


Fig 1-9

a drawing medium (another lead bath). The speed of the wire through these media is of critical importance.

Matempering

In this process the part being treated is quenched from a temperature at which its structure is wholly austenitic to a temperature just above the M_s temperature. This is done in a salt; or molten metal, bath. The part is held at this temperature as long as possible without running the risk of getting any transformation to bainite and is then quenched to room temperature. The object of the delay at the first quench is to allow the temperature of the part to be equalized throughout as much as possible, but clearly the delay must be less than the incubation period at the matempering temperature. The process is similar to the very old "patenting" process used in the manufacture of spring wire and which consists of passing the wire through a heating medium (lead bath), a quenching medium (an oil bath) and finally through

Austempering

In this process the part being treated is quenched at a sufficient rate to avoid transformation to ferrite and pearlite and is held at the quench temperature for a time sufficient to give complete transformation to bainite and is then cooled to room temperature. It is claimed that the process gives greater ductility in carbon steels which are tempered to hardnesses of about 50 Rockwell C (approx. 520 D.P.N) than would be given by fully hardening and tempering to the same hardness value and that in certain steels the creep properties will be improved.

HEAT-TREATING FURNACES

Heating steel for the purpose of annealing, hardening, tempering, etc., may be carried out in a number of different types of furnaces. The choice of any furnace depends largely upon the type of heat-treating operation and upon the size and tonnage of the steel involved. Large-scale heat-treating operations are carried out in batch type or continuous type furnaces which are equipped with a means of automatic temperature control and mechanical devices for the handling of the steel in and out of the furnace and into the quenching baths. A great many of the furnaces are designed and constructed to carry out some specific heat-treating operation; accordingly, a great diversity of types and designs of furnaces are in use.

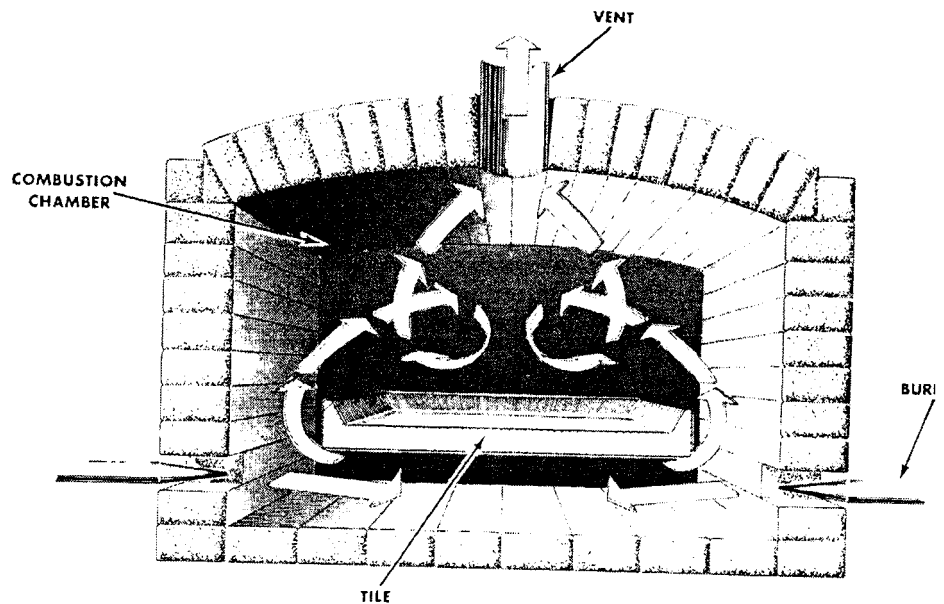


Fig .1-10 The principle of the semi-muffle type furnace

Furnaces are of the oil-fired, gas-fired, or electric type. Oil-fired or gas-fired furnaces may be designed as direct-fired, semi-muffle, or muffle. The direct-fired furnaces allow the steel to come into direct contact with the hot gases of combustion and are mainly used for heating steel for forging operations. The semi-muffle type is so designed that the gases of combustion are deflected and do not impinge directly upon the steel being heated, although

they circulate around it. This affords better control of the heat, which results in a more uniform product. See Fig.1-10

In order to protect steel from oxidation during any heat-treating operation, furnaces of the full-muffle type are commonly used. These full-muffle furnaces are so constructed that they provide a chamber, known as the *muffle*, separate from the combustion chamber, into which the steel to be heated is placed. The gases of combustion circulate around the chamber or muffle and cannot come in contact with the steel being heated. See Fig.1-11

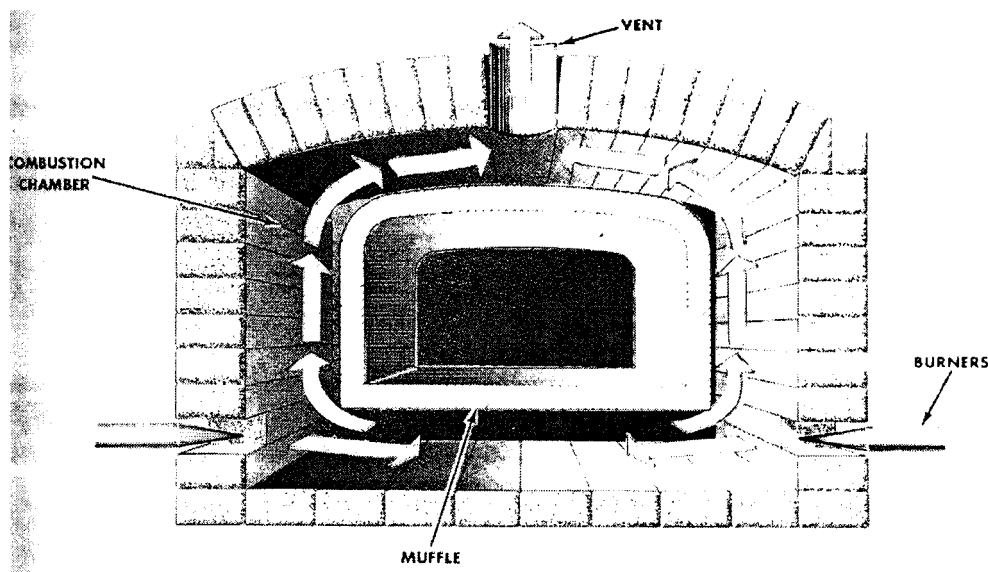


Fig.1-12 The principle of muffle type furnace

In the electric-type furnace, the resistors are usually placed around the outside of the muffle. The muffle is made of a special heat-resisting alloy or special refractory material. The hot gases of combustion, or in the case of an electric furnace, electric resistors, heat the muffle and the steel within the muffle. A neutral or reducing gas may be supplied to the interior of the muffle so as to greatly increase the degree of protection afforded the steel during the heat-treating cycle. The full-muffle type furnace is commonly employed with the so-called atmosphere-type furnace and is used when maximum protection from oxidations is required. See Fig.1-12

Metallurgy

Recent improvements in heat-treating furnaces have been made possible because of improved heat-resisting alloys for muffles and other parts, improved refractories, more efficient burner equipment, improvement in temperature control apparatus, and better electric resistor alloys.

Furnace Atmospheres

Heating steel in an electric furnace or in a muffle furnace in the presence of air results in the oxidation of the steel surfaces with the formation of scale and loss of surface carbon (decarburization). The ideal atmosphere is one, which will not scale or burn out carbon

(decarburize) during the heating operation. In order to obtain this ideal atmosphere, artificial gas atmospheres are added to the heating chamber in a muffle or electric furnace.

Bottled gases such as methane, propane, ammonia or city gas are frequently burned in endothermic (heat absorbing) gas generators. Endothermic gas generators are those in which heat is supplied in order to crack the gases and provide atmospheres generally composed of hydrogen, nitrogen, water vapor, methane, carbon monoxide and occasionally oxygen. With the exception of nitrogen, all of these gases react with steel, causing oxidation, carburization or de-carburization.

The selection of the ideal gas atmosphere for the heating chamber depends upon many factors, such as the type of steel being treated, the temperature of the operation, etc., and requires a careful study of the problem involved an understanding of the reactions occurring at the temperature of operation. In general, this problem is solved by trying several gaseous mixtures and analyzing their effect upon the steel being treated. Some commonly employed gas atmospheres are shown in Table.1-2

TYPICAL APPLICATION	GAS CONSTITUENTS—PERCENT BY VOLUME					
	CO ₂	CO	H ₂	CH ₄	H ₂ O	N ₂
NO. 1 Case carburizing low or medium-carbon steels	----	20.7	38.7	0.8	----	39.8
NO. 2 Bright annealing copper	10.5	1.5	1.2	----	0.8	86.0
NO. 3 Process annealing copper, low-carbon and stainless steels	0.05	0.05	3-10	----	----	Remainder
NO. 4 P/M sintering—bright annealing (cracked anhydrous ammonia)	----	----	75.0	----	----	25.0

Table 1-2 Prepared gas atmospheres used in heat treating operations

The most common gas mixtures contain a relatively high percentage of CO or H₂, both of which are reducing gases, and may be used to prevent the formation of surface scale or decarburization. The presence of CO₂, or O₂ in the gaseous atmosphere may result in harmful and excessive scale or surface decarburization. However, this will depend upon the type of gas used the type of steel, and the temperature of operation. In general, the atmospheres used in any heat-treating operation are such as to produce a light scale, thus preventing decarburization to a depth of more than 0.001” all of which could normally be removed in any finishing operation.

Liquid Heating Baths

Another type of heating equipment commonly employed in heat treating operations is the pot type furnace used for liquid heating baths such as shown in Fig.1-13

Both molten lead and molten salt baths are used for the heating of steel in operations involving hardening, annealing, tempering, etc. Molten lead is a fast-heating medium and gives complete protection to the surfaces of the steel. With a melting point of 621°F (327°C), lead may be used successful from 700°F to about 1600°F (370-870°C). Lead oxidizes readily with the formation of a dross, making a dirty bath, and gives trouble because of the sticking of lead and dross to the surfaces of the steel being heated. This can be

overcome by suitable lead coverings such as wood charcoal, coke, carburizing compounds, slats, etc. The steel can be further protected from lead sticking to its surfaces by the use of a coating of a thin film of salt or some other material, which is applied to the steel before it is placed in the lead bath. Dipping of warm steel into a saturated brine solution and allowing it to dry leaves a protective salt film on the steel. The use of a water emulsion containing bone charcoal, rye flour, potassium ferrocyanide, and soda has proved successful. The steel is dipped into the emulsion and allowed to dry before placing in the lead bath.

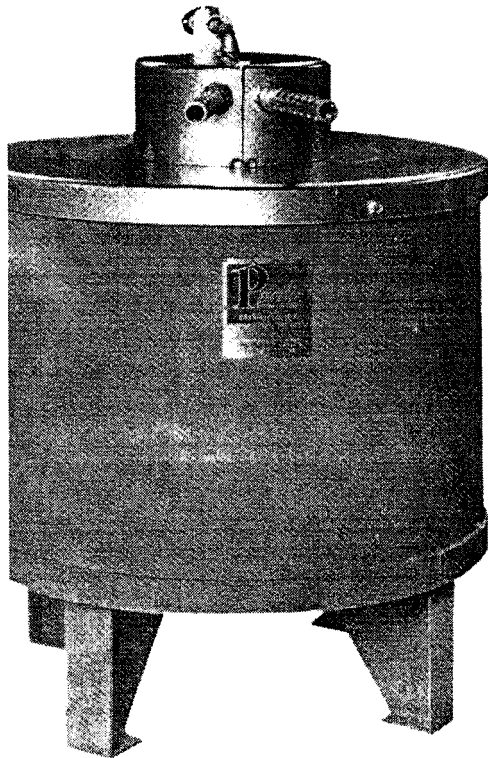


Fig.1-13 Pot type electric furnace

baths are made from mixtures of barium chloride, borax, sodium fluoride, and silicates. Precautions should be observed in the use of salt baths in order to prevent moisture from coming into contact with the fused salts. With the cyanide salts, precautions should be observed because of their poisonous nature.

Pyrometers

For modern heat-treatment furnaces the above method of measuring temperature is not very convenient because it is lengthy in operation and does not give a continuous reading of the temperature, as it often necessary. A more scientific and reliable method of measuring furnace temperatures is by an instrument called a *pyrometer*. There are various forms of pyrometers and two types in common use are: (1) The Thermo-Electric Pyrometer, (2) the Optical Pyrometer. The first type makes use of the principle that when two dissimilar wires

Molten salt baths have been found to be satisfactory for the heating of many steel parts that are to be given heat treatments. They transmit heat quickly and uniformly and afford a protection to the steel during the heating cycle. Upon removal of the steel from such a salt bath, a thin film of salt adheres to it, giving further protection from air prior to the quenching, etc. Although the ideal salt bath has not been discovered, if care is used in the selection of a salt and precautions are exerted in its use and maintenance, good results may be expected.

Salts may be used for low-temperature tempering. They usually consist of nitrates and may be used in a range of temperatures from 300°F to 1000°F (149 to 538°C). Salt baths used in temperature ranges of 1000°F to 1650°F (about 538 to 895°C) consist mainly of sodium carbonate, sodium chloride, sodium cyanide, and barium or calcium chloride. In a temperature range of 1800°F to 2400°F (980° to about 1315°F) salt

are joined to form a complete electric circuit, and the two junctions maintained at different temperatures, an electric current flows in the circuit, the magnitude of the current depending upon the metals used, and the temperature difference of the junctions. The *hot junction*, which is placed in the furnace, is often made up of wires of platinum, and an alloy of platinum and rhodium welded together and is called a *thermocouple*. Leads from these wires are carried to a sensitive galvanometer which generally constitutes the cold junction, and which indicates the current flowing in the circuit due to the difference of temperature between the two junctions. The galvanometer is so calibrated, that instead of indicating electrical units, it reads in degrees of temperature. A diagram of this pyrometer is shown at Fig.1-14

The *optical pyrometer* compares the intensity of light being emitted from the furnace with that from some standard source. In the disappearing filament pyrometer the glow of a standard filament lamp is varied until it matches the light from the furnace and disappears when viewed through the telescope. The instrument, which is shown diagrammatically at Fig., is set up in front of the furnace and the light from the furnace is viewed through the eyepiece. The current through the lamp is varied by a resistance, and when a colour match is obtained the lamp current required to ammeter. This instrument may be calibrated so that it reads in degrees of temperature, instead of in units of electric current. The appearance of the filament, as seen through the telescope, is shown alongside the diagram Fig.1-14

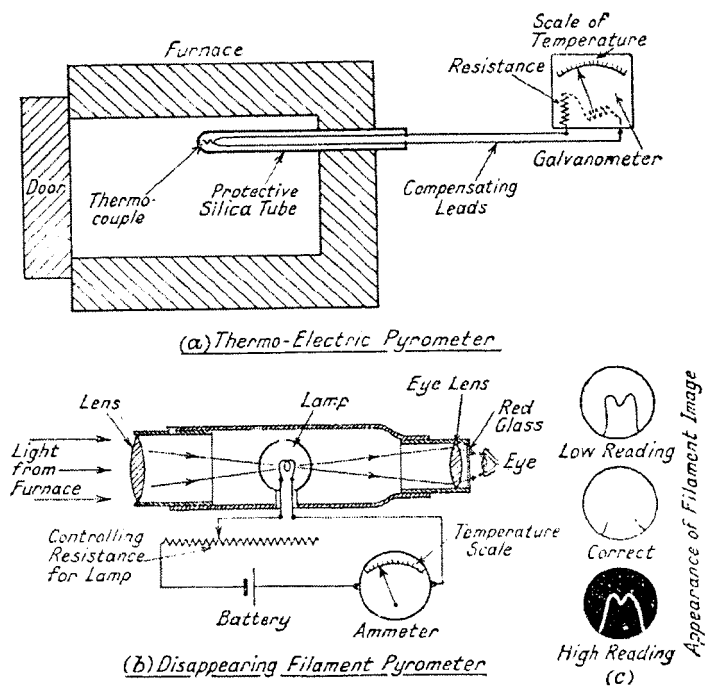


Fig.1-14 Methods of measuring Furnace temperature