

CHAPTER 3

METALS AND ALLOYS

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General

1. Metals and alloys are divided into two categories and classified as ferrous and non-ferrous, each with its own characteristics. Alloys of metals may be made with two or more elements included in the same group or with suitable elements from each group, so producing changes in the metals concerned. These changes may be in the form of improvements in grain structure to increase the strength or to give some entirely new property to a metal, *e.g.* resistance against corrosion. In aircraft design the primary consideration is the reduction of weight with increase in strength and with this objective in view, together with due consideration of other desirable qualities, alloys of various metals have been developed. In the production of metals and alloys the correct chemical composition and the control of temperatures during heating processes is very important. Metals and alloys used in the construction and repair of aircraft must conform to D.T.D. Specifications or British Standards Specifications. The metals available are easily identified by means of various colours as laid down in the Air Ministry Standard Colour Scheme (see Sect. 5 of this A.P.) A general description of ferrous and non-ferrous metals and alloys as used in the construction and repair of aircraft is given in the following paragraphs. Degrees of temperature are given throughout this chapter in Centigrade readings which may be converted if necessary to Fahrenheit readings by means of the following formula:—

$$\text{Fahrenheit} = \left(\frac{9}{5} \text{ Centigrade} \right) + 32.$$

Specifications

2. Specifications of metals and alloys used in the Service consist of those issued by D.T.D. and the British Standards Institution. In these specifications all information is given regarding the composition, heat-treatment required and physical tests relevant to a particular metal or alloy; other particulars given concern the uses and the methods to be adopted for preparing test pieces. The compositions of metals and alloys are also given with the percentage of each element included, which may vary in some instances within the limits given in the specification. When any element has a deleterious effect upon a metal it is classed as an impurity and the total amount of impurities must be kept below a specified percentage. The effect of each element should be fully understood whether the element is regarded as an important constituent or as an impurity; for example, the percentage of carbon present in steel gives an indication of its suitability for hardening purposes, but consideration should also be given to other elements that will alter the effect of the carbon, as in the cases of manganese, nickel or chromium. A list of elements is given below with various values

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relevant to each. The physical tests shown in D.T.D. and B.S. Specifications are those which are considered necessary for particular metals and are designed to prove that they are free from defects and have desirable qualities which render the metals suitable for the purpose for which they have been produced. Particulars of heat-treatment are given in detail where it is considered necessary, and maximum and minimum temperatures, quenching mediums and any important features peculiar to the metal concerned are also included in the specifications.

Characteristics

3. The characteristics of metals and alloys give each its own particular use for constructional purposes. Pure elements have their own characteristics, most of which may be utilised alone, as, for example the lightness and ductility of aluminium, the high conductivity of copper or the non-corrosibility of nickel. These characteristics, however, may in many instances be improved and other desirable qualities given to metals by alloying and heat-treatment. A typical example of the improvements and alterations that are possible in the characteristics of metals and alloys is shown by the large variety of steels now produced which have entirely new qualities not possessed by the original cast iron.

List of Elements

<i>Element</i>	<i>Symbol</i>	<i>Specific Gravity</i>	<i>Melting Point C°</i>	<i>Weight per cu. ft. in lb.</i>
Aluminium	Al	2.60	658	168
Antimony	Sb	6.62	630	412
Cadmium	Cd	8.65	321	540
Carbon	C	2.22	—	—
Chromium	Cr	7.14	1630	440
Cobalt	Co	8.9	1480	545
Copper	Cu	8.94	1083	550
Iridium	Ir	22.4	2405	1395
Iron	Fe	7.6	1530	470
Lead	Pb	11.35	325	707
Magnesium	Mg	1.74	652	109
Manganese	Mn	7.2	1230	450
Molybdenum	Mo	10.2	2620	—
Nickel	Ni	8.85	1452	540
Phosphorus	P	1.82	44	—
Platinum	Pl	21.45	1772	1344
Silicon	Si	2.4	1420	—
Silver	Ag	10.5	960	654
Sulphur	S	2.07	112	—
Tin	Sn	7.3	232	455
Titanium	Ti	4.5	1800	280
Tungsten	W	19.3	3370	1200
Uranium	U	18.7	1690	—
Vanadium	V	5.68	1710	—
Zinc	Zn	7.14	419	440

4. In aircraft construction, such light weight metals as aluminium and magnesium are used extensively, and various alloys containing these elements have been developed whereby with very slight increases in the specific gravity, a greater strength-weight ratio has been obtained, as for example in the cases of duralumin and copper-hardened aluminium. A metal may have all the desirable characteristics required in use except that machining may be found to be almost impossible, in which case the addition of some new element may give good machining qualities without affecting the other properties; the addition of nickel to some types of cast iron is an example of such a case. In other instances a metal may be increased in strength by hot or cold working or by heat-treatment. The specific gravity (see para. 3) of a metal gives its density compared with an equivalent volume of water having a unit weight of 1.00.

5. The grain structures of different metals vary widely in shape, size and density. The shape and size of the grain structure can be varied by alloying, heat-treatment and hot and cold working; these processes cause chemical changes, inter-granular changes, and changes in grain direction which give certain qualities to metals. Throughout the production of metals and alloys, close control of heat is necessary and this has been made possible by the use of suitable meters that give temperature readings, electrically from thermo-electric pyrometers, by relative light intensities, or by the use of cones made from materials which are known to melt at certain temperatures, one example of the latter type being the sentinel which is available to the Service and listed in A.P.1086.

6. In order to understand fully the effect of alloying metals one with another and the various changes which take place due to different heating and working processes, a brief reference to the

properties and chemical compositions of various metals is necessary. The properties are self-explanatory and include hardness, softness, toughness, brittleness, malleability, tenacity, elasticity, ductility, fusibility, conductivity of heat or electricity and non-corrosibility. Methods of testing and appliances for testing metals have been devised in order to decide the relative degree to which various characteristics are possessed by a metal. The relevant Specifications should always be referred to in instances where full particulars regarding the composition and general treatment of metals and alloys are required, and the descriptions of them given in this chapter should be regarded as a general indication of the nature, uses and limitations of the metals employed in aircraft construction.

Testing

7. Metals and alloys are developed and heat-treated in order to obtain or improve the properties required in the finished article for the particular purposes for which it is to be used. In order to ensure that the properties are obtained correctly to the degree required, and to ascertain whether undesirable properties have been eliminated or not, it is essential that tests are made during the course of production. In many instances, tests are necessary up to the final stage when the metal is put into use, especially so in the case of metals to be used in the construction and repair of aircraft; several such tests are dealt with in B.S. and D.T.D. Specifications with details of the manner in which the tests must be made. A brief survey of various tests will be found below.

Chemical analysis

8. Samples of metals are taken from the ingots or from the moulds, care being taken to ensure that the test pieces are representative of the whole. Test pieces may be taken after this stage by drilling out samples for test. The metal cuttings so obtained are then subjected to various applications of heat or acids that will determine the presence and percentage of the constituents, separate processes being used according to the nature of the element and the presence of other elements in the alloys under test; this is a highly specialised process and is only undertaken by skilled metallurgists. A further chemical process is chemical etching, used in testing prepared specimens by submitting a highly polished face which has been produced on the test piece, to the effect of various etching solutions containing nitric, picric or other acids; the nature of these solutions varies according to the elements included in the metal or alloy. Chemical etching may be used to show the depth of case hardening, the direction of grain and grain size, or it may be used to show the nature of welds. Photographs with magnification up to 5,000 diameters may be taken of polished, etched or fractured test pieces and used to show the general grain structure. Photomicrography is used extensively in connection with metals for the purpose of recording the effect of heat treatment upon the structure of the metal.

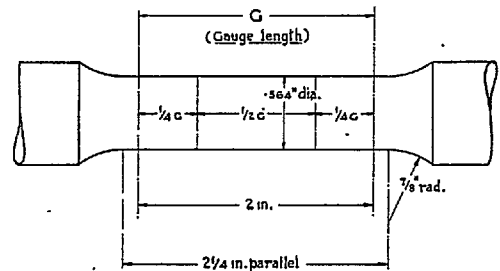


Fig. 1.—Example of tensile test piece

Tensile test

9. Tensile tests are made on standard test pieces (see fig. 1) suited to the material being tested, of a particular specified length and cross-sectional area. The ends of the specimens are usually larger than the area to be tested and the specimen is adapted to the type of machine in which it is to be tested. The testing machine stretches the specimen and at the same time gives a reading on a scale of values that are indicated throughout the test. The values to be noted are the yield point, the ultimate breaking strength, the amount of elongation and the reduction in cross-sectioned area; the resultant values of the first two being expressed in tons or pounds per square inch. Examples of such tests, specimen sizes and values to be obtained during the tests are contained in various B.S. Specifications.

Bending tests

10. Bending and flattening tests are made by approved methods on test pieces of tube, strip or sheet metal as described in D.T.D. and B.S. Specifications; descriptions of proof bend tests, hydraulic tests and tests for metal and tubes of various cross-sections are also given therein. These tests are made before the material is issued for use and they vary in the angle to which the test piece is to be bent, the radius of the bend, and the number of bends made; this test ensures that the metal is

suitable for the purpose for which it is to be used and indicates any liability to cold-shortness or the presence of seams and other defects that may be due to impurities in the metal or to errors in heat-treatment. A test for brittleness in wire is made by means of a wrapping test; for the purpose of this test the wire is wrapped eight times round its own diameter and then unwound, leaving the last turn, without showing signs of fracture. A torsion test may be given to wire by turning or twisting the wire a specified number of times for unit lengths equal to a standard number of diameters, as given in the relevant specification; the number of turns is usually 20 per length of wire having a length equal to 100 diameters.

Hardness tests

11. Hardness tests are made on metals by various methods most of which depend upon the application of a known pressure to an object so producing an indentation of varying width for different degrees of hardness. The measurements given are relative only and the tests referred to in the B.S. and D.T.D. Specifications are the Vickers Diamond Pyramid and the Brinell hardness tests; these are the generally accepted standard tests. Another type of hardness tester is known as the Scleroscope and the hardness values given on this machine depend upon the height of the rebound of a diamond tipped weight or hammer which is dropped from a certain fixed height upon the test specimen.

12. The Brinell test is made with a hard steel ball 10 mm. diameter which is placed on the test piece and a pressure of 3,000 kilograms is then applied to the ball for a period of not less than 15 seconds but for relatively hard metals this period is often extended to 30 seconds; a pressure of 500 kilograms is applied for a period of 60 seconds when testing softer metals. The tests are not reliable when dealing with material less than 0.50 in. thickness. The diameter of the ball impression is obtained by taking the average of two impressions from tests made at an angle of 90 degrees; from this average diameter the hardness number is derived by means of the following formula:—

$$H = \frac{P}{\frac{\pi D^2}{2} (D - \sqrt{D^2 - d^2})}$$

when H = Brinell hardness number.

P = load in kilograms.

D = diameter of ball in millimetres.

d = average diameter of ball impressions in millimetres.

13. The Vickers test in which a square base pyramid diamond is used to make an indentation on the test piece, includes the application of a pressure which may be varied between 5 kilograms and 120 kilograms for a period of 30 seconds; measurement is made across the diagonals of the impression of the diamond on the test piece by means of a microscope. The following formula is applied to obtain the hardness number from the length of the diagonal:—

$$\text{Hardness number} = 1.8544 \left(\frac{L}{d^2} \right)$$

d = length of diagonal in mm.

L = load in kilograms.

Impact tests

14. Impact tests are made to determine the brittleness of such metals as cast iron and heat-treated steel; this test is generally referred to as the Izod test. The test specimen (see fig. 2) of the required standard dimensions is prepared to the correct length and cross-section and a notch of known depth is cut. The specimen is then gripped in a vice in the testing machine in such a position that the hammer will strike the specimen when a pendulum of standard weight and length is released; the angle of the swing of the pendulum past the lowest point is measured along a graduated sector upon which the energy absorbed in breaking the specimen is directly indicated in ft. lb. The Izod value given in a test should be correct for the type of steel under test and its tensile strength, therefore the value will vary for different types of steel also for different tensile strengths of any one type, given by heat-treatment or working processes. If the steel has not been heat-treated correctly the Izod value will be lower than the specified value for that particular type of metal. The testing machine used is the Izod Impact Tester. In instances where the Izod notched bar test is considered impracticable or a fracture is required to be examined, a nicked bar test is substituted using a test piece nicked or sawn in such a manner that the area of the portion to be fractured is not less than one-half of the cross-sectional area of the bar.

General effects of heat

15. Metals and alloys are affected in various manners by heat applied during the course of production and subsequent heat-treatment. The control of heat, especially at certain critical temperatures, will have a decided influence on the characteristics and properties of metals, usually by changing the structure. Examples of such structural changes are noticeable particularly in the

cases of cast iron, tool steel and duralumin. Casting, cold working, uneven sections, and rapid or uneven cooling, will induce internal stresses in metals which can be removed by careful heat-treatment. The reduction of these stresses is dependent on plastic movements which take place when the correct amount of heat is applied for a requisite period of time, the cooling being arranged in order to ensure that other new stresses are not introduced. The rate of heating, the period of time over which heat is held and the rate of cooling, are all important factors in heat-treatment processes; steel, for example, should not be placed when cold in a highly heated furnace but the temperature of the furnace should be raised slowly and maintained for a period of time sufficient to allow for the heat to reach the centre of the metal, long pieces of steel being supported during the process to prevent sagging. The heating medium and gasses evolved within the furnace may affect heated metal by carburising or oxidising it and high temperatures and long periods of heating may cause excessive grain growth and oxidation with consequent weakening of the metal. Liquid baths may be employed for heat-treatment for which purpose water, oil, lead, lead and tin, and salt baths cover a wide range of temperatures. Salt baths protect the metal from the harmful effect of furnace fumes and air, and provide rapid heating and ensure uniformity of temperature. Before any process is commenced involving the application of heat to metals it should be ensured that the character of the metal is known and that the process to be used is the correct one for the metal in question. Metal which has been exposed to excessive heat cannot be restored to its original state by heat-treatment, but must be re-smelted.

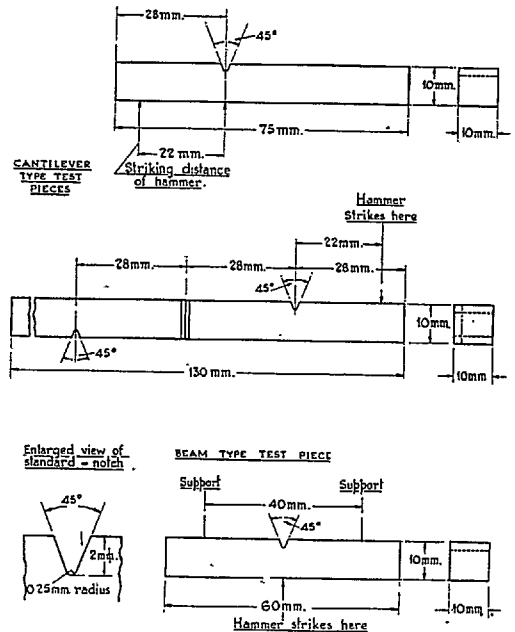


Fig. 2.—Standard notched bar dimensions

Pyrometers

16. In order that the high temperatures involved may be accurately gauged during the production and heat-treatment of metals and alloys, different types of pyrometers are used; those in general use are the thermo-electrical, the optical and the sentinel types. The thermo-electric pyrometer (see sketch I and II, fig. 3) embodies the application of the thermo-couple principle, i.e. if two wires of suitably different metals are joined together at one end and subjected to a sufficiently high temperature at the juncture, a small electric pressure is generated across the free ends. This pressure can be measured by means of a milli-voltmeter having a temperature scale, the resultant reading on the scale registering the changes in the temperature of the heated juncture when the free ends are maintained at a constant temperature that may be within the range of from 0 to 24 degrees Centigrade, allowance being made for slight fluctuations. The wires forming the thermo-couple must be capable of withstanding the effects of the heat applied and must have an electrical potential difference sufficient to give a reading on the milli-voltmeter. The combination of metals most frequently used in instruments registering temperatures up to 1650° C. is a platinum wire with an alloy wire of platinum and 10 to 15 per cent rhodium. For the protection of the platinum wires against the higher temperatures, the hot junction may be enclosed in a porcelain or ceramic tube; the thermo-couple in use should not come into contact with the flames otherwise the temperature reading shown on the scale will be higher than the true furnace heat.

17. In instances where a thermo-couple pyrometer cannot be used for the measurement of high temperatures some form of optical pyrometer should be used (see sketch III and IV, fig. 3). This type measures the intensity of the heat by the relative brightness of the heated object to that of a suitable standard light intensity. One type in use makes comparison with the heated object and the brilliancy of a lamp filament varied by a suitable resistance. In another type the lamp filament intensity of light is maintained at a constant standard value whilst the variation of the furnace brilliancy is measured, by means of alterations in the position of a wedge-shaped prism, which is moved until the intensity of light appears to be the same in both instances. The latter types of pyrometers are seldom used for gauging temperatures below 900° C. as the luminosity within the furnace below this point is difficult to match, also smoke and incandescent gases give errors in reading and readings taken may vary with individual observers.

18. Pyrometric cones are used for the measurement of heat temperatures; these are made in the form of triangular pyramids and are composed of various substances that are known to fuse at certain temperatures. The cones are graded and each grade is numbered in order to indicate small increases in the fusing points of the cones up to temperatures as high as 2,000°C., thus a cone can be selected to fuse at the temperature required for the work, and another cone of a slightly lower fusing point can be used as a warning to indicate that the critical temperature is almost reached, whilst a third cone can be used to indicate the safe maximum temperature for the work in hand and beyond which the work must not be heated.

Application of heat

19. The heat treatment of metals and alloys varies in accordance with the chemical compositions and with the purpose for which they are to be used. The heat at which temperature the desired constitutional changes take place should be applied in such a manner that it is carried to the core of the metal without burning or unduly scaling the exterior. Maximum temperatures should be held long enough to attain uniformity of temperature consistent with the area of the cross-section and the thermal conductivity of the metal. The rate of heating for non-ferrous metals is proportionally slower than for ferrous metals in accordance with the increase in the melting point. Direct impingement of the furnace flame on metals and alloys should be prevented and scale should be removed if present on the material or in the furnace, because this has a decarburising effect on ferrous metals which may form soft patches or spots on the material. Metals should be heat-treated as required at the temperatures given in the relevant B.S. and D.T.D. Specifications.

FERROUS GROUP OF METALS AND ALLOYS

20. The ferrous group of metals and alloys comprises those having iron as the base. The group may be sub-divided into two parts, i.e. (i) cast iron and its alloys, (ii) steel and its alloys. Brief descriptions of these metals most generally used for aircraft construction and repair are given in the paragraphs below.

Cast iron

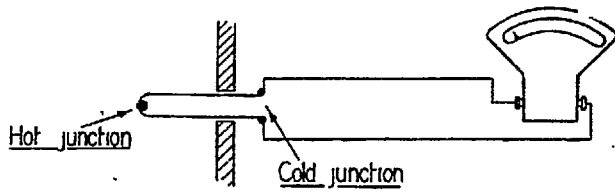
21. Cast iron is produced from iron ore which is converted by smelting processes into various grades of pig-iron; these are not of use for constructional purposes until re-smelted, the chemical composition adjusted and the metal cast into the desired form. The following table gives the analyses of two grades of pig-iron available to the Service on demand and listed in Air Publication 1086; the table also gives an indication of the composition of a typical cast iron alloy:—

Elements	Foundry No. 1	Foundry No. 3	Chromium Cast Iron
	Percentages		
Carbon (graphite)	3.00 to 3.50	3.25	3.20
Carbon (combined)	—	0.24	—
Silicon	2.50 to 3	3.00 to 3.50	0.70
Sulphur	0.04 (max.)	0.03 (max.)	0.10 (max.)
Phosphorus	1.20 to 1.50 (max.)	1.10 to 1.40 (max.)	0.20 (max.)
Manganese	1.20 to 1.50	0.80 to 1.20	0.90
Chromium	—	—	0.35

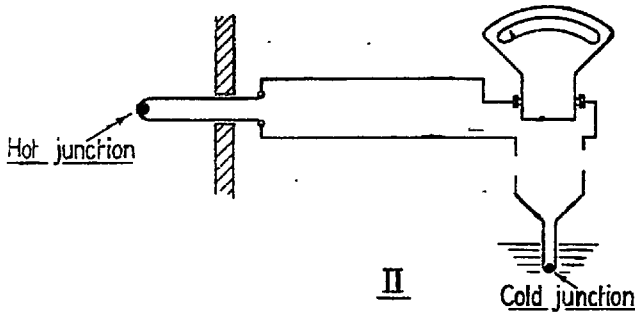
Cast iron alloys

22. The desirable qualities in cast iron can be improved by means of alloying with other elements; particulars of all such alloys are to be found in the relevant B.S. and D.T.D. Specifications, but for convenience those in frequent use are dealt with in a general manner in the following sub-paragraphs:—

- (i) *Nickel iron.*—The addition of 0.25 to 5 per cent nickel improves the texture of cast iron and gives better machining qualities and increased resistance to wear and corrosion, with a reduction in the coefficient of expansion. When the amount of nickel is increased from 10 to 18 per cent, the alloy changes in structure and becomes austenitic with high resistance to scaling at temperatures up to 815° C. the alloy is less liable to corrosion by the action of many acids, alkalis, etc.
- (ii) *Chromium cast iron.*—Chromium cast iron has a reduced graphite-carbon content, effected by the addition of the chromium. Additions of 0.30 to 1 per cent chromium gives a uniform fine grain structure to the metal and when the amount of chromium is increased to 3 per cent the graphite content disappears, the alloy showing a very white fracture when broken. Chromium also gives an increase in the tensile strength at higher temperatures and reduces the tendency of castings to growth. If the basic cast iron is hard the resultant alloy may be too hard to machine although the amount of chromium may be as low as 0.25 per cent; the addition of nickel reduces this hardening effect.

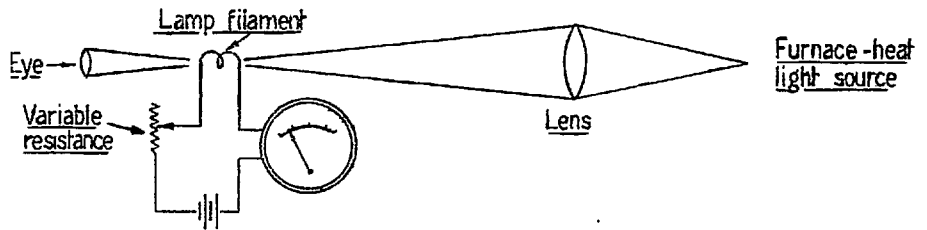


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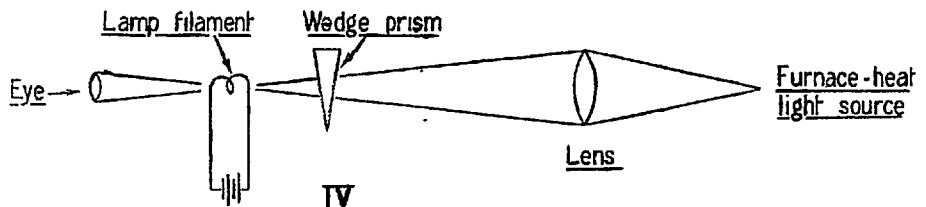


II

THERMO - ELECTRIC



III



IV
OPTICAL

Fig. 3.—Metals and alloys—pyrometers

- (iii) *Nickel-chromium cast iron*.—Nickel and chromium may be used together to produce cast iron alloy with a range of qualities suitable for particular classes of work. The addition of these elements is usually from 0.50 to 1 per cent. chromium and up to 3 per cent. nickel, giving a refined grain structure with increased hardness and strength without increasing machining difficulties. The use of chromium also obviates lowering the silicon content in the cupola mixture which would be necessary if nickel was used alone. The Brinell hardness number of this alloy is approximately double that of ordinary white cast iron. The alloy produced by mixing grey cast iron, 1.50 per cent nickel and 0.50 per cent chromium, is harder and tougher than the base cast iron, and is machined more easily. Nickel-chromium castings may be hardened by air cooling directly they are removed from the red hot moulds.
- (iv) *Molybdenum cast iron*.—Molybdenum may be added to cast iron in quantities varying from 0.25 to 1.25 per cent and its action is to form carbide and increase the tensile strength and hardness. The influence on grey cast iron is greater than that of any other element for producing increase in the strength. The maximum increase in strength is obtained when the quantity of molybdenum added is about 2 per cent, but over this amount there is a decrease in the tensile strength of the alloy. Molybdenum retards the various changes that takes place in the alloy throughout the full range of temperatures, during heating processes. This alloy also has good wearing qualities, and has a uniform structure even in heavy sections.
- (v) *Vanadium cast iron*.—Vanadium additions to cast iron are carbide forming in effect and the resultant alloy has a very fine grain and a more even distribution of fine graphite flakes than the base cast iron. The alloy is harder and tougher with increased effect of chill to a greater depth than is usual with the original cast iron due to stabilisation of the cementite caused by the presence of vanadium. The amount of vanadium usually added to cast iron varies from 0.10 to 0.50 per cent.
- (vi) *Titanium cast iron*.—The alloy formed by the addition of titanium to cast iron is similar in character to a silicon iron and has a reduced reaction to chill. The size of the graphite particles in the alloy is reduced and this results in an increase in the tensile strength. Titanium is mostly used in more complex alloys containing other elements such as chromium, vanadium or molybdenum.
- (vii) *Aluminium cast iron*.—Aluminium cast iron with an aluminium content of 1 to 1.75 per cent is used for the production of an alloy that may be hardened by the nitride process, by means of which an extremely hard wearing surface is formed. With this alloy the persistent formation of oxide during the pouring of the molten metal is a disadvantage, because the skin of oxide becomes thicker as pouring proceeds, resulting in the production of unsound castings.

Malleable iron

23. Malleable iron consists of cast iron which has been annealed for a period of about 10 days in close contact with a substance containing iron oxide such as red hematite. By this process a structural change is effected in the grain of the iron and a semi-steel skin is formed by the absorption of carbon which takes place during annealing; the core remains practically unchanged. Good malleable iron castings machine very freely, and will withstand shock loads much better than cast iron. Malleable iron cannot be welded by the same process as that used for cast iron or steel, but it can be bronze welded satisfactorily should an occasion arise where repair will suffice.

Wrought iron

24. Wrought iron is produced from refined pig iron by subjecting it to various processes during which carbon, silicon, phosphorus and sulphur are almost eliminated by oxidisation; these elements are considered to be impurities and should not be present in wrought iron in quantities above a limited amount. Wrought iron is a very ductile metal and has a very coarse fibrous grain structure in one direction caused by the rolling processes involved. It is easily forged and welded and can be case-hardened satisfactorily. When wrought iron is subjected to further treatment by heating over a period of several days in contact with charcoal, blister steel is produced which is used in the production of crucible cast steel.

Steel

25. Steel is produced from cast iron by several methods; these methods vary in the processes which reduce the amount of carbon and silicon and eliminate such undesirable elements as sulphur and phosphorus. The chief processes used are the crucible cast, open hearth, Bessemer and electrical smelting. These processes depend mainly upon the oxidising effects of an air blast on molten iron and they vary in the method of applying the heat and air, also in the type of fluxes employed for

different grades of iron used. Although strictly speaking all steel is an alloy it is usually classified under two groups, i.e. plain carbon steel and steel alloy. Carbon steels are divided into three classes, namely, low carbon, medium carbon, high carbon.

Steel alloys

26. A number of steel alloys have been developed for special purposes, several of the alloys having particular applications in aircraft construction. The new elements which are added to the metals in widely varying quantities may be used singly or in several combinations in order to produce alloy steels for some specific purpose. The effects of some elements may be to improve grain structure, to give increased hardness, toughness and ductility, or in the case of stainless steel to resist corrosion. The most frequently used alloy steels are dealt with in the following sub-paragraphs:—

- (i) *Nickel steel.*—Nickel steel has several new properties in comparison with carbon steel. The addition of nickel increases the tensile strength and the yield point and gives increased hardness without loss of ductility when the steel is in either the annealed or heat-treated state; the alloy is invariably used after heat-treatment in order that full advantage may be taken of the properties given to the alloy by the nickel. Critical temperatures are spread over a wider range during heat-treatment and the alloy can also be subjected to relatively high temperatures for long periods without undue injury to the metal. Nickel steel is particularly suitable for case-hardening, a deep and uniform penetration of carbon combined with a very tough core, being obtained by this process. The quantity of nickel in one particular group of nickel steel alloys is usually between 0.50 per cent and 6 per cent; higher percentages of nickel are used in other groups in order to obtain special alloys. Electrical resistance wires may be made from a 25 to 30 per cent nickel alloy whilst a 35 per cent alloy is used for the production of invar which has a coefficient of expansion that is practically zero, and is non-magnetic; for these reasons invar is used in the manufacture of scientific instruments. Alloys with a 50 per cent nickel content are used for their magnetic properties as they have a high permeability at low field strengths. Nickel is also used in the more complex alloys in conjunction with chromium, silicon, tungsten, etc.
- (ii) *Chromium steel.*—Chromium is alloyed with steel alone, or with nickel or other elements. The addition of chromium in producing chromium steels is 0.50 to 1.50 per cent, added in the form of ferro-chromium. Special air-hardening steels are made from chromium steel, the chromium content being from 12 to 17 per cent and carbon from 1 to 2.25 per cent; higher percentages of chromium are used in the manufacture of stainless steels of which there are many types each having a different composition and characteristics for some particular purpose. The high chromium content is common to all these steels but there are two groups. The first group consists of alloys with a low nickel content, and these can be hardened and tempered by heat-treatment, they are magnetic and are resistant against corrosion in the heat-treated condition only. Alloys in the second group have a high nickel content and they cannot be hardened by heat processes and are non-magnetic. Hardening is effected by working the material and softening or annealing is effected by heating it to a temperature of 1100° C. and then cooling rapidly. Forging temperatures are very high, being in the region of 980° C. and 1100° C. The chief properties of austenitic steels are resistance to corrosion and scaling and capacity for withstanding high temperatures. Stainless steel is manufactured in a variety of forms and may be cast, rolled, forged or drawn, and for each of these purposes it is possible to vary the composition of the alloy in order to give a particular property. Typical specifications of these alloys are given in the relevant B.S. and D.T.D. Specifications.
- (iii) *Manganese steel.*—Manganese steel is very tough and has the property of work hardening slowly, and becomes hard and brittle if allowed to cool. Pearlitic manganese steels are frequently used, the manganese content of which is usually from 1 to 1.90 per cent, the carbon content being from 0.10 to 0.50 per cent. This alloy is usually quenched in oil during hardening processes and when the carbon content is high it is dangerous to quench it in water. Austenitic manganese steel contains from 11 to 15 per cent manganese and a carbon content of 1 to 1.40 per cent and is so tough and hard that the metal hardens as the tool is being forced into the work. During machining operations, the correct speeds and feeds should be used, special high-speed tools also are necessary. If the carbon content exceeds 1.40 per cent the alloy decreases in toughness and strength. The result of adding manganese to steel is for the manganese to (i) combine with some of the carbon and form carbide of manganese, (ii) act as a purifier by eliminating gases and oxides, (iii) combine with any sulphur, nullifying its harmful effect. The critical temperatures

for manganese steel are increased in range so facilitating heat-treatment processes, the range from minimum to maximum being as high as 65° C. in some instances. Austenitic manganese steel has an electrical resistance seven times that of pure iron, is practically non-magnetic, and can be cast, forged and rolled.

- (iv) *Cobalt steel.* Cobalt is very similar to nickel in appearance and in its properties, and it is usually alloyed with steel for use in the production of permanent magnets and high-speed tool steel. Tungsten vanadium steel alloys may be improved by the addition of cobalt which has the effect of making the alloy less sensitive to critical temperatures during heat-treatment processes. The amount of cobalt required for the different alloys varies considerably, e.g., from 1 per cent to 12 per cent is used for tool steels and 35 per cent for steel suitable for the production of permanent magnets. Special heat-treatment is necessary for all cobalt steels after forging otherwise cracking may result during cooling.
- (v) *Tungsten steel.*—Tungsten is added to some steel or steel alloys in order to produce high-speed steels with special heat-resisting qualities. Tungsten is a carbide forming element and quantities of 0.50 per cent may be used for steels employed in the production of dies, etc., but the quantity added may be as high as 20 per cent in the case of special high-speed steel. Magnet steel may be produced containing from 5 to 7 per cent tungsten, but cobalt steel is more efficient for the purpose.
- (vi) *Silicon steel.*—Silicon steel alloy usually contains silicon in combination with other elements such as chromium and manganese. Silicon acts as a deoxidiser and assists in producing steel which is practically free from blowholes. The percentage of silicon in the alloy varies in accordance with the qualities required in the finished product and with amounts of silicon up to 4.5 per cent the tensile strength and yield point are increased. Silicon-manganese steel is used commercially for the manufacture of flat leaf springs, and silicon-chromium alloys are used for making valves for internal combustion engines in which the high temperature conditions are destructive to ordinary steel.
- (vii) *Vanadium steel.*—Vanadium steel is close-grained and uniform in structure and in use has great resistance to shock and fatigue. The usual quantity of vanadium added is from 0.18 to 0.20 per cent and the effect on the steel is to produce the quality of toughness and a high elastic limit, also an increase in tensile strength, without loss of ductility. Vanadium steel alloys respond well to heat-treatment and are used in the production of large forgings because of the low degree of distortion. Vanadium is also used in more complex steel alloys containing chromium, manganese and nickel; these alloys may be both forged and cast. Tool steels invariably contain a percentage of vanadium as this element gives increased cutting ability, especially when alloyed with tungsten steel. Chrome vanadium steel alloy is employed in the manufacture of valve springs for aero-engines.
- (viii) *Molybdenum steel.*—Molybdenum steel alloys contain pure molybdenum which is a soft ductile metal similar in colour to platinum. The percentage of this metal in the alloy composition is between 0.25 to 0.40, but may be as high as 1 per cent if alloyed with manganese. The effect of molybdenum on steel is to slow down any structural change caused by heat-treatment and to give greater depth to hardening; it also gives toughness, structural stability, higher temperature strength and absence of temper brittleness. The alloy is not difficult to work and may be rolled, forged and welded, and in addition the tendency to cracking during heat-treatment is reduced. When the molybdenum content is low it does not affect the forging, rolling, machining or welding properties of the alloy. Molybdenum is mostly used in conjunction with other elements such as chromium and manganese to give increase in tensile strength or additional depth-hardening qualities.

NON-FERROUS GROUP OF METALS AND ALLOYS

General

27. The following paragraphs contain information regarding the most important of the non-ferrous metals and alloys, used in the construction and repair of aircraft and aero-engines. An indication is given in a general manner of the nature of the alloys by means of typical examples of the chemical compositions, etc., but in all instances when precise particulars are required regarding any metal and alloy reference should be made to B.S. and D.T.D. Specifications; it should be noted that different specification numbers may be given to one alloy in various states of hardness or of different formation as in sheet or tubular form, etc. In the non-ferrous group are included the light alloys, which are of special interest in connection with aircraft work. Brief descriptions are also given which are intended as a guide when gauging the relative properties and the behaviour of metals when they are subjected to heat, and which may be used for guidance in the processing and in the application of the metals and alloys in question.

Aluminium

28. Aluminium is a light-weight metal obtained chiefly from bauxite, four pounds of which is required to produce one pound of pure aluminium. In its pure state aluminium is very soft and ductile and has a specific gravity of 2.60. It is rarely used in the pure state owing to its low maximum strength but is often alloyed with copper, tin, nickel, manganese, zinc and silicon. An alloy may contain one of these metals only, added to the aluminium to form a simple alloy, or it may contain various combinations of several metals added in varying amounts to form complex alloys. Aluminium can be worked by most of the usual processes, e.g. rolling, spinning, drawing, extruding, forging, casting and welding. It has a high conductivity of heat and has a high coefficient of expansion although in some alloys the latter characteristic is reduced considerably. Aluminium is electro-positive to copper, iron, lead, tin, nickel and zinc, and contact with these metals, particularly when moisture or salt spray is present, will cause rapid deterioration of the aluminium caused by corrosion. Brief descriptions of the most important of the aluminium alloys are given in the following subparagraphs:—

- (i) *Duralumin*.—Duralumin is an aluminium-base alloy and has a specific gravity of 2.80; the usual composition is about 4 per cent copper, 0.50 per cent manganese, and 0.50 per cent magnesium. Special properties are given to the alloy by heat-treatment, mechanical working and by varying slightly the percentages of the alloying elements. Under certain conditions duralumin has the peculiar property of age-hardening and advantage is taken of this phenomenon in the preparation of the alloy for aircraft purposes. Duralumin can be annealed by heating to a temperature of 370° C. and then cooling in air or water; local annealing is permissible if the whole is subsequently normalised. The metal should not be left for long periods in its fully annealed condition because in this state it is very susceptible to corrosion. Normalising consists of heating the metal to a temperature within the range of 480° to 500° C. and then quenching in water. It is after this process that age-hardening occurs, maximum hardness being reached in a period of from 1 to 4 days. For convenience normalised parts can be stored in a cold-chamber with the temperature maintained at 0 degree Centigrade in order that the age-hardening process will be delayed for short periods. If this is done, the process is entirely suppressed for 24 hours only, after which the process commences at a reduced rate. If local melting takes place during the heating of duralumin caused by the application of excessive heat the alloy cannot be used unless re-cast and forged. Baths of molten salts are employed for the purpose of heat-treating duralumin and the salts used are a combination of potassium and sodium nitrates. In common with most other metals duralumin is subject to corrosion, particularly if exposed to sea water spray. A certain amount of protection can be given by anodic treatment consisting of the electrical deposition of a film of aluminium oxide on the surface of the duralumin. Sheet duralumin coated on both sides with aluminium is known as alclad, and is made by heating and rolling a sheet of duralumin between two sheets of pure aluminium at a sufficiently high temperature to ensure fusion of the surfaces in contact. The protection against corrosion is effected electrolytically, the aluminium coating being electro-negative to the inner duralumin.
- (ii) *Aluminium-copper alloy*.—This alloy is relatively hard and is suitable for the production of die-cast pistons, carburettor bodies, etc. The composition is about 88 per cent aluminium and 12 per cent copper, the copper acting as a hardening element serves to maintain the original properties of the alloy at relatively high temperatures. The alloy is susceptible to corrosion, which is due to the effect of the copper content, therefore its uses are limited to parts which are not exposed to corrosive influences.
- (iii) *Aluminium-magnesium alloy*.—Aluminium magnesium alloy has a high resistance to fatigue and surface corrosion and is suitable for casting. Aluminium is the basic constituent of the alloy which contains also between 3 and 6 per cent magnesium and 0.25 to 0.75 per cent manganese. A suitable alloy for the production of sheet metal has a magnesium content of 3 to 6 per cent and a maximum strength of 20 tons/sq. in., which is approximately twice that of pure aluminium sheet. There are several similar alloys in this class having slight variations in the chemical composition to which small additions of chromium, manganese or silicon, are made.
- (iv) *"Y" alloy*.—"Y" alloy is an aluminium alloy containing 4 per cent copper, 2 per cent nickel, 1.50 per cent magnesium and the remainder aluminium. This alloy is highly resistant to corrosion and will withstand heat of relatively high temperatures without losing its original properties and is often used in the manufacture of drop-forged pistons and cylinder heads. "Y" alloy responds to heat-treatment in a similar manner to duralumin and is also subject to age-hardening. The alloy can be cast or wrought and although the maximum strength is lower for the cast alloy than for the wrought, an improvement in the cast alloy can be effected by suitable heat-treatment.

- (v) *Aluminium-silicon alloy.*—Several different aluminium-silicon alloys are used to produce castings which are malleable and which have a low coefficient of expansion. The silicon content of such alloys is usually between 8 to 13 per cent with small additions of copper, manganese and other hardening and modifying agents. Included in this class of alloy are those known commercially as Alpax and Hiduminium. More complex alloys containing smaller amounts of silicon are used for the production of sheets, tubes and extruded bars. The addition of titanium to some of these silicon alloys gives a fine grain structure which is present in both the cast and wrought alloy.

Copper

29. Copper is commercially produced as a 99.95 per cent pure element and it can be employed in its pure state or alloyed with other metals. The important features of copper are that it is ductile, malleable, and tough while it has the property of good conductivity of heat and electricity. It is manufactured in a large variety of forms and can be obtained in sheets, bars, wire and as tube. Copper can be freely worked and can be work-hardened, annealed or electro-deposited; annealing consists of heating the metal evenly to a temperature of 650° C. and then quenching in water or allowing to cool in the air. A brief description of the chief alloys of copper are given in the following sub-paragraphs:—

- (i) *Brass.*—Brass is the general term used for the copper-zinc alloys, other terms used to indicate different types of alloy are gun metal, phosphor-bronze, etc. There are two main groups of brass, which include those used when cold-working the brass into sheets, wire or tubes and those which are suitable for casting, hot-working or extruding; the first group has a copper content of about 65 per cent and a zinc content of 35 per cent, and the second group has approximately 60 per cent copper and 40 per cent zinc. Brass, when it is worked cold becomes harder, but it may be annealed by heating to a temperature of 600° C., the annealing period being the time taken by the metal to attain the correct temperature. If the required annealing period is not quite completed the grain of the metal is restored but is small in size whilst over-annealing causes an increase in the grain size with surface deterioration. To remove internal stresses in brass the heat required will be of a much lower temperature than that necessary for annealing; the temperature is 250° to 270°C., which should be applied for a period of half an hour to one hour. Brass has a good resistance to corrosion and corrosion fatigue, and this property is improved by adding 2 per cent of aluminium to the alloy. The addition of 2 to 3 per cent lead to brass gives greatly improved machining qualities but reduces the ductility, the lead breaking up into minute globules, so making the metal short. High tensile brass is the hot working type to which has been added from 0.5 to 3 per cent of each of such elements as iron, aluminium, tin, nickel and manganese, and is generally used for extruded work, etc. Brass can be worked by hand, and is easily machined; it can be joined by soft and hard soldering, or by brazing. It is particularly suitable as a basis metal for such processes as nickel and chromium plating. Brass foil may be obtained in thicknesses ranging from 0.002 in. to 0.012 in. Sheet brass, brass wire and the thickness of the walls of tube are usually measured and graded to S.W.G.
- (ii) *Aluminium-nickel-silicon brass alloy.*—This alloy is known as Tungum, and is produced in sheet and tube form; it is very tough and has a high resistance to fatigue and corrosion. The copper content of a typical specification ranges from 81 to 84 per cent with zinc from 11 to 14 per cent and 1 per cent each of aluminium, nickel and silicon. Tungum tube is very strong and ductile, having a maximum stress of from 28 to 38 tons/sq. in.
- (iii) *Bronze.*—Bronze is an alloy of copper and tin with a small amount of zinc, and may be obtained rolled, drawn or cast. It is used in the manufacture of small parts of aero-engines such as bushes, valve guides, etc. Cast bronze is not suitable for use in highly stressed parts because of its uncertain character. The addition of phosphorus in very small amounts forms phosphor-bronze, which is superior in mechanical strength to ordinary bronze; the phosphorus content varies from 0.10 to 0.50 per cent. Careful control of the critical heat temperatures and of the cooling rates is necessary in order to obtain the correct distribution of the phosphorus in the alloy. Hard-drawn phosphor-bronze bars are produced with a maximum strength of 30 to 40 tons/sq. in.
- (iv) *Copper-lead alloy.*—Copper-lead alloys have been developed to produce a bearing metal that will withstand high loading stresses and which will have good mechanical strength and good adhesion to the metal of the bearing shell. The copper content of this alloy is usually 70 per cent and the remainder is lead with 1 per cent tin.
- (v) *Copper-nickel alloy.*—Copper-nickel alloys are very ductile and are highly resistant to corrosion. They are produced mostly in sheet form and can also be rolled and extruded. The nickel content is high, being usually about 70 per cent, with the remainder copper

and a small percentage of manganese. Copper-nickel alloy, or cupro-nickel, has been successfully employed in the construction of radiators of aircraft and in making inserts for aero-engine valve seats.

Lead

30. Lead is a very soft white metal and because of its low mechanical strength and high specific gravity its use on aircraft is very limited. Lead is resistant to atmosphere corrosion and to the corrosive effects of most acids, but it is attacked by both soft water and nitric acid. Combinations of lead alloy and lead oxides are used for the manufacture of the plates of accumulators of the lead-acid type. Lead is also included in the formation of solders of a low working temperature and in certain grades of white-metal bearing alloys. Lead pipes can be joined by means of a process known as "wiping", the metal being worked whilst it is in a plastic state during the operation. Sheet lead is usually welded by means of a process known as lead-burning.

Magnesium

31. Magnesium is the lightest of all the commercial metals, having a specific gravity of 1.74. It is used extensively in the manufacture of various aircraft components and forms an important constituent of a number of complex alloys, e.g. duralumin, "Y" alloy and the alloy commercially known as elektron. Magnesium is available in two forms, one being the familiar magnesium powder or strip which burns with a brilliant flash and the other being that used in the production of castings, forgings, extruded rod and sheet metal. Ordinary foundry practice cannot be used when casting magnesium as this metal reacts violently when in-contact with moisture at, or above, melting point; green sand moulds cannot be used without the addition of an inhibitor such as sulphur, ethyl glycol or boric acid. To counteract the effect of the light weight of the metal during casting, "risers" of large cross section must be used. Magnesium alloy sheet can be worked cold for simple operations, but if heated to a temperature of 300° C. it becomes more amenable to bending, although in this condition it is only suitable for the formation of bends which are not acute. The principal metals used with magnesium for alloying purposes are aluminium and zinc, in addition, however, small quantities of copper, nickel and manganese are sometimes used. When magnesium is alloyed with aluminium, it combines with the silicon and forms a hard compound, the hardening effect being very marked although the quantity of silicon added may be relatively small. Magnesium can only be welded when the metal does not contain more than 3 per cent of other elements. Particulars of the chief magnesium alloys are given in the following sub-paragraphs:—

- (i) *Magnesium-aluminium alloy.*—Magnesium-aluminium alloy is particularly suitable for the production of rolled, forged, extruded or drawn work. Heat-treatment is not necessary to produce the maximum strength unless the alloy has been specially annealed. It is lighter than duralumin, having a specific gravity of 2.63. In its hard condition it has a maximum strength of from 26 to 30 tons/sq. in. which is reduced to 20 tons/sq. in. when the alloy is in the annealed state; the alloy must not be heated during processes where it is not required to be annealed, to a temperature exceeding 100° C.
- (ii) *Cast magnesium alloy.*—Particulars of magnesium alloys suitable for casting will be found in B.S. and D.T.D. Specifications. The specific gravity of these alloys is slightly greater than for magnesium alone, and is usually from 1.81 to 1.83. The compositions vary slightly in the percentages of the alloying elements and the properties are varied by heat-treatment. The percentage of aluminium in these alloys ranges from 8 to 11 per cent, that of zinc from 1 to 3.5 per cent, the manganese content being up to 1 per cent. These alloys are often used for the manufacture of die-cast pistons, crankcases, carburettor bodies, etc.
- (iii) *Wrought magnesium alloy.*—Wrought magnesium alloys have a relatively high aluminium content with low percentages of zinc; 11 per cent aluminium, 1.5 per cent zinc and 1 per cent manganese, the remainder magnesium, is a typical example of the composition of an alloy suitable for forming extruded bars and forgings. It is a ductile alloy and has a good resistance to fatigue, the maximum strength ranging from 15 to 17 tons/sq. in.

Nickel

32. Nickel is a hard white metal which is very ductile, it can be welded and will withstand heat of very high temperatures. It is used chiefly in the formation of a very large range of alloys of the ferrous and non-ferrous groups. Nickel is highly resistant to corrosion and is used for nickel-plating which may be employed alone or as a base for chromium plating. Monel metal is a nickel alloy with a nickel content of about 70 per cent, the remainder being copper to which a 2.5 per cent addition is made of other hardening elements such as manganese and iron. This alloy is sometimes

used for the seats of aero-engine valves because of the capacity to retain its strength when subjected to heat at high temperatures and its resistance to the corrosive effects of the products of fuel containing lead. Nickel alloy sheet and strip is made from an alloy containing from 43 to 48 per cent nickel, 21 to 25 per cent zinc, small amounts of manganese and iron and the remainder copper. This alloy is practically non-corrosive and can be annealed, without causing any surface damage, by heating to a temperature of 780° C., followed by air or water cooling. This alloy in its soft state is used for making wire, tubes, rivets and pins.

Tin

33. Tin is a soft white metal which is very ductile but, whilst it is rarely used in the pure state, it forms an important constituent of several different alloys. It is obtainable mostly in ingot form of various grades, ordinary standard commercial grades being about 99.75 per cent pure. The property possessed by tin of amalgamating at relatively low temperatures with various other metals, is used to advantage in the formation of bearing metals and alloys used as solder. An indication of the nature of some of the more important alloys having a large tin content is given in the following sub-paragraphs:—

- (i) *White-metal*.—White-metal, sometimes classified as copper-tin alloy, is used as a bearing metal because of its anti-friction properties, its toughness and its capacity for melting at a temperature low enough to prevent seizing in the event of a bearing overheating. A typical composition of one of these alloys is copper from 5.50 to 7.50 per cent, antimony 6 to 7 per cent, nickel not more than 0.60 per cent, and the remainder tin. There are various other grades which are included in B.S. and D.T.D. Specifications.
- (ii) *Solders, Grades A and B*.—These solders listed in A.P.1086 are alloys of tin, lead and antimony, and are employed for different classes of work. Grade A solder contains 65 per cent tin, antimony up to 1 per cent and 34 per cent lead, and has a melting point of 180° C., whilst Grade B solder is composed of 50 per cent tin, antimony between 2.50 and 3 per cent and the remainder lead, and this solder has a melting point of about 225° C. The total impurities in both are limited to 0.25 per cent. Grade B solder is used for general work, radiator and tank repairs, etc., whilst Grade A solder is used only for specified work where lower working temperatures are necessary. Other grades of solder with special properties are included in B.S. and D.T.D. Specifications.

Zinc

34. Zinc in its pure state is a soft ductile metal having a low tensile strength. It is strongly electro-negative to other metals and is very resistant to atmosphere corrosion; it can be applied, as a protective coating, to sheet iron, wire ropes, etc., by means of hot-dipping and electro-depositing processes. Zinc is alloyed with several other metals, including copper, aluminium, magnesium and cadmium; an alloy of cadmium and zinc is used for the purpose of soldering zinc-coated metal parts and this solder contains 71 per cent cadmium and 29 per cent zinc, both metals being 99.95 per cent pure. When zinc is subjected to excessive heat it is very volatile and for this reason alloys containing zinc should be heated carefully; the fumes given off by volatilised zinc are injurious to health and should not be inhaled.



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