ALLOYS AND INTER-METALLIC COMPOUNDS

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Introduction:

"When two or more elements are melted together and resulting liquid is allowed to solidify, the product so obtained is called an alloy, if it possesses metallic properties".

With exceptions all the components in an alloy are metallic elements. Thus an alloy may consist of mixture of a metal with metal or metal with non metal.

Rarely, an alloy may consist of a single phase only. In this case the alloy tends to have the softness, malleability and ductility of a pure metal: e.g. for all compositions, mixtures of silver and gold form a single phase.

Most often an alloy consists of two or more phases in equilibrium. Each phase has specific crystal structure different from each others. For example five phases are present in the copper-zinc alloy which constitutes ordinary brass (પિત્તળ).

It is important to note that alloys are homogeneous in molten state, but in solid state they may either be homogeneous or heterogeneous. Alloys having mercury as the constituent element are termed as *'amalgams'*. For example sodium-amalgam is an alloy of sodium and mercury. In alloys the chemical properties of the component elements get retained, but certain physical properties get improved.

Effect of Alloying:

Alloys are manufactured because they have properties more suitable for certain applications than do the simple metals. In many cases it is harder and stronger than a pure metal. In other instance, alloys are used because they have especially desirable casting properties, special physical properties such as magnetic or especially desirable resistance to corrosion in certain environments. However, some of principal effects of alloying on the properties of metal are as follow.

1. For Decreasing Melting Point:

Melting point of alloy is normally lower than melting point of either pure component. Moreover, an extended melting range of temperature exists. This is sometimes advantageous as for example, in the use of lead-tin alloy as solders where an extended working range of temperature is required through which the metallic mixture

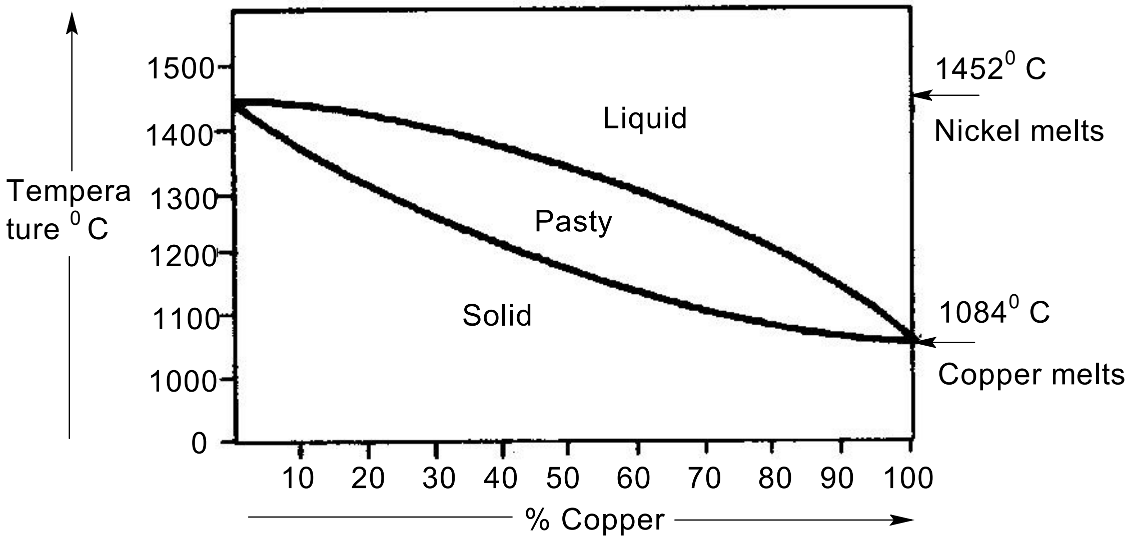


Fig. 2.1 Melting point of copper-nickel alloys

exists as semi-solid paste. This fact is utilized in making useful alloy called solders.

2. For increasing Hardness of the Metal:

Pure metals are generally soft, whereas alloys are harder than its constituent elements. For example, lead is a soft metal but its alloy having 0.5 **%** arsenic is so hard that it finds use for making bullets.

We know that, pure iron is soft, however its alloys with 0.15-1.5% carbon (steels) very hard and finds use for making machinery parts. Similarly, pure gold and silver are to be mixed with copper for making jewelers, coins etc.

3. For increasing Tensile Strength:

Alloys have greater tensile strength than the base metal. For example, addition of 1% carbon enhances the tensile strength of pure iron by 10 times. Similarly, addition 1% chromium or nickel to mild steel enhances its tensile strength.

4. Corrosion Resistance:

As pure metals are reactive, they are easily corroded by atmospheric gases, moisture etc. On the other hand, alloys are more resistance to corrosion than the pure metals. For example bronze (કાસુ) is an alloy of Cu and Sn which is more corrosion resistant than copper resistant. Stainless steels are known for its corrosion resistance, whereas iron gets corroded even by moist air. Brass, an alloy of Cu and Zn does not get attacked by sulphuric acid while Zn gets attacked.

5. For increasing Castability Property:

Expansion of material on solidification has been essential requirement for its use as casting material. However, pure metal usually contrast on solidification, while alloys expand on solidification. For example, type metal (alloy of lead with 5% tin and 2% antimony) finds use for casting printing type.

6. Corrodibility: This is frequently markedly reduced. Stainless steel, Duriron, German silver alloys show this effect.

7. For modifying colour: Alloy formation is also accompanied by change in the colour of constituent metals. For example, brass alloy is yellow, whereas Cu is red and Zn is silver-white.

8. Thermal and electric conductivity: Both these properties are normally reduced. For example, chromel (Cr+Ni) are made into resistance wires for electric heaters because of their relatively high resistivity's.

Properties of Alloys:

1. **Melting point:** Pure molten metal solidifies at its melting point. But if another metal is dissolved in that molten metal, then mixture of

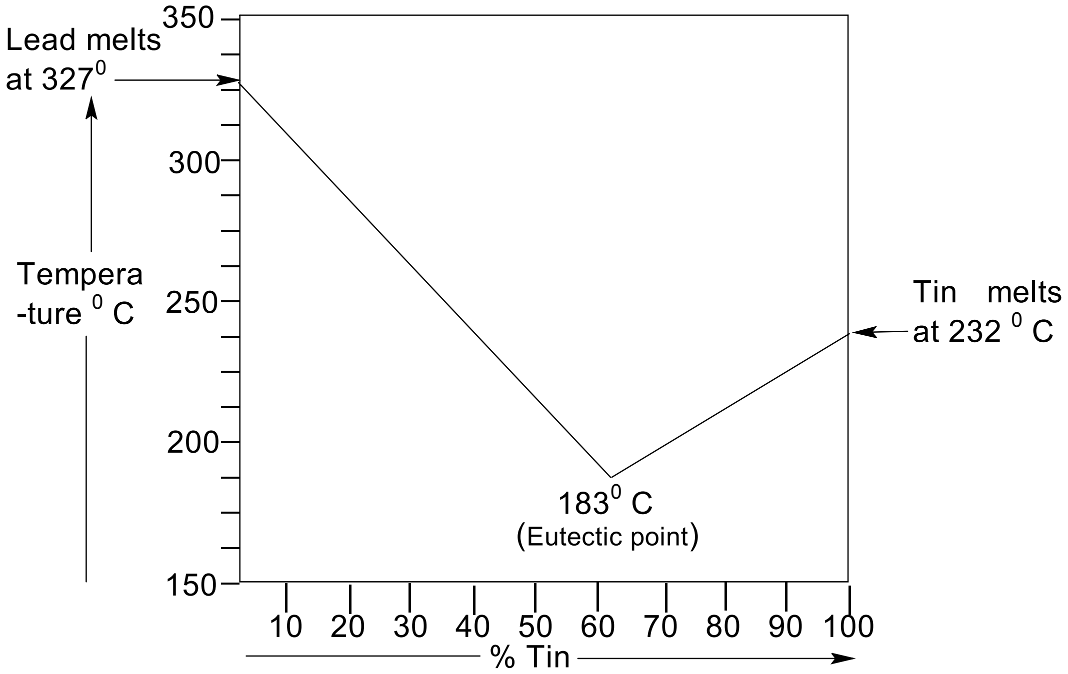


Fig. 2.2 Melting point of lead-tin alloys

two metals solidify at a temperature lower than the freezing point of pure metal.

Nickel melts at 1452^0 C and copper at 1084^0 C. But 50-50 mixture of these two metals melts at about half way between these two temperatures. Pure metal melts as well as freezes at definite temperature. But 50-50 mixture if cooled slowly it start freeze at 1312^0 C and as temperature decreases more mass becomes solid until finally entire mixture is solidified at 1284^0 C (Fig. 2.1).

There are two lines drawn between melting point of pure nickel and pure copper. For particular composition between these two line the alloy is in paste form.

Pure Pb-melts at 327^0 C and melting point decreases as the proportion of tin in lead-tin alloy increases until it reaches 62% with that of lead at 38%. This is the lowest melting point of lead-tin alloy and very much lower than melting point of either of two metals. As the proportion of tin increases, the melting point goes up towards that of pure tin (M.P. 232^0 C). The mixture of 62% tin and 38% lead behaves as pure metal and freezes suddenly at 183^0 C, such alloy is called **"eutectic alloy"** (eutectic in Greek means easily melted).

Eutectic alloy: "It is that proportion of metal which melts or freezes at the lowest temperature".

The temperature 183^0 C is called eutectic temperature.

2. **Hardness:** Hardness and strength depends in: (i) Grain size (ii) Lattice structure of metal involved.
   i. **Grain size:** Generally, small grained metals are likely to be harder and stronger than big grained. Copper-nickel alloys

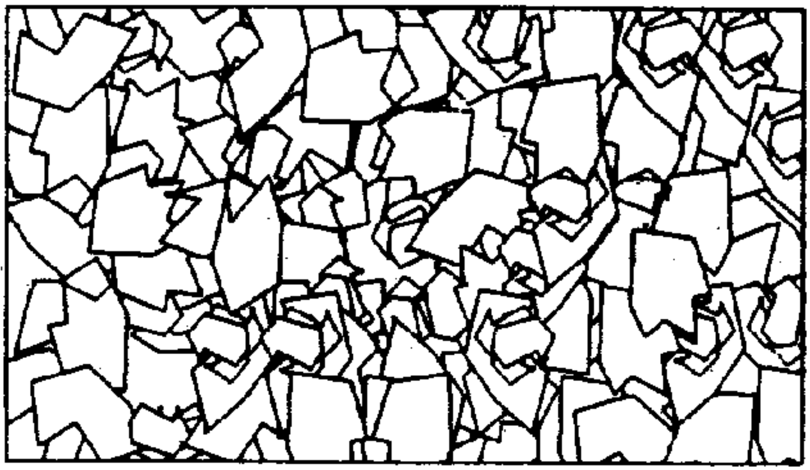


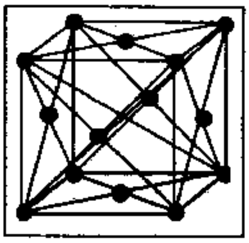
Fig. 2.3

show only one kind of grain (Fig. 2.3). But in copper-zinc (brass) show two distinct kinds of grain are seen. The black and white areas do not represent neither pure copper nor pure zinc, but two kinds of copper-zinc solutions (Fig. 2.4).

Fig. 2.4

In another type of alloy, a solid solution of two metals surrounds and encloses individual grain of an inter-metallic compounds. Hot metal will dissolve more of alloying metal, but on cooling their ability to dissolve will decreases. For example, at 419^0 C aluminium can dissolve 5% of copper, but as temperature decreases, the amount of copper in solution decreases to become 1% at room temperature. The 4% copper does not separate out of alloy but forms compound with aluminium which is widely dispersed throughout the alloy as tiny island of extremely hard $CuAl_2$. Such compounds are called inter-metallic compounds. Pure aluminium is soft. But Al with 1% Cu in solution and 4% in inter-metallic compound form has the toughness of the solid solution and the hardness of the inter-metallic compounds, $CuAl_2$. Inter-metallic compounds are present in most of alloys but their right proportion in alloy is important. Too much $CuAl_2$ in 50-50 copper-aluminium alloy makes the alloy very hard, but it is brittle and not useful.

During alloy formation some atoms of one metal will replace the atoms of the other metal in its lattice. Since, there exists the difference in the size of atoms of different metals; the distortion in the lattice of the *'base metal'*, takes place. The distorted lattice is more difficult to push or pull out of its new shape. Therefore resulting alloy becomes harder and stronger than the individual metals.



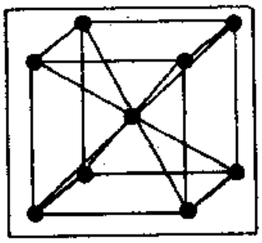


Fig. 2.5 Face-centred cubic lattice. Fig 2.6 Body-centred cubic lattice

ii. **Lattice structure:** Each pure metal has characteristic lattice form. For example, "Face-Centered Cubic and Body-Centered Cubic lattice".

3. **Electrical Conductivity:** Metals are good conductors of electricity. The electric current is carried by electrons which are free to migrate through crystal. The electrons can collide with atoms which correspond to the resistance to the flow of electric current. The magnitude of current decreases with increase in number of collision between the atoms and electrons.

   Highly pure metal has least resistance to the flow of current. But when impurity atoms dissolved which acts as scattering centre for conduction of electrons and cause the increase in the resistance of metal.

   In an alloy the solute atom perturbs the regularity of the crystal structure of the solvent (base metal) and acts as a scattering centre for the conduction of electricity which result in increase the resistance of the metal.

   In dilute solid solution the effect of solutes on the resistivity's governed by two rules.

   - **Mathiessen's rule:** "The increase of resistance of metal due to small concentration of other metal in solid solution is independent of temperature".
   - **Linde's rule:** "The increase of resistance of metal due to a given atomic percent of solute atom is proportional to the square of the difference of atomic number between solute and solvent".

Preparation of Alloys:

The properties of alloy cannot be predicted even if it is prepared from the known quantities of the metal. For example, alloy of 50% copper and 50% aluminium may be expected to have average hardness and color of two metals. But none of these things happens. In fact such an alloy is very hard, very brittle and hence useless. Alloys can be prepared by the following methods.

i. **Fusion method:** This method involves fusing together components of alloy in proper proportion in refractory bricks-lined crucible. If the component metal have different melting point, the metal with higher melting point is melted first and lumps of the other metal having lower melting point are then added to melt. This is carried out to avoid loss of low melting metal by volatilization. The molten mass is thoroughly stirred with graphite rod for uniform mixing. In case of metals are having different densities the heavier component is mixed later to avoid it's settling, otherwise alloy of uneven composition is obtained.

As the molten metal's are at high temperatures they are liable to get oxidized by atmosphere, to avoid this difficulty the surface of molten mass has to be covered with layer of powdered carbon. Then molten mass is cooled slowly when solid alloy is obtained. Brass alloy is prepared by this method.

If the melting point of constituent metals of alloy are considerably differ, e.g. m. p. of copper is 1084^0 C and that of zinc is 420^0 C, whereas the boiling point of zinc is 906^0 C. Thus b. p. of zinc is 178^0 C lower than m. p. of copper. Therefore, if zinc and copper are melted together Zn will volatizes. The problem can be solved by melting Cu first and then adding solid Zn in to molten Cu, where it is quickly dissolved. However 20% of zinc is lost due to volatilization. Therefore extra quantity of zinc has to be added to prepare an alloy of proper proportions. Another problem arises when melting point of the metal of smaller proportion is higher of two. For example, an alloy of 92% aluminium (m.p.-650^0 C) and 8% copper (m.p.-1084^0 C) when prepare, the porous material is obtained. To avoid this difficulty first hardener alloy (50-50) is made which has lower m. p. than either of the two metals. Now base metal (Al) is melted and appropriate quantity of the hardener alloy is then added to get desire alloy. In making steel alloys Si, Cr, Mn are added to hardener alloys which are mixture of these metals and known as ferrosilicon, ferrochromium and ferromanganese respectively.

ii. **Reduction method:** In this method the reduction of suitable compound (oxide) of one metal by other constituent metal of the alloy occurs. For example, aluminium bronze is obtained by reducing alumina in presence of Cu in electric furnace.

iii. **Electro-deposition method:** In this method there occurs the simultaneous deposition of different component metal from the electrolytic solution having their salts solutions by passing D. C. electricity e.g. brass.

iv. **Powder metallurgy or Compression method:** In this technique the mixture of two or more metal powder is subjected to great pressure at temperature just below m. p. of alloy.

Advantages:

- The rate of formation of alloy is high
- It’s operation is clean and quit, no material gets wasted.

Types of Alloys: There are five different types of alloys.

1. **Simple mixtures:** Here constituent metals are insoluble in each other like water and oil form separate layer.
2. **Solid solution:** Here constituent metals are completely soluble in liquid state like water an alcohol. The atoms of one metal fit themselves into the crystal lattice of the other. Two metal having same crystal structure and similar chemical characteristic can form solid solution.
3. **Substitutional alloys (metallic alloys):** Mixture of metal with metal, atoms of one metal replace at random, the atoms of another metal in the crystal lattice of the latter. They can form continuous range of solid solutions. This type of alloy formed if the radii of the component metals are identical or nearly so.

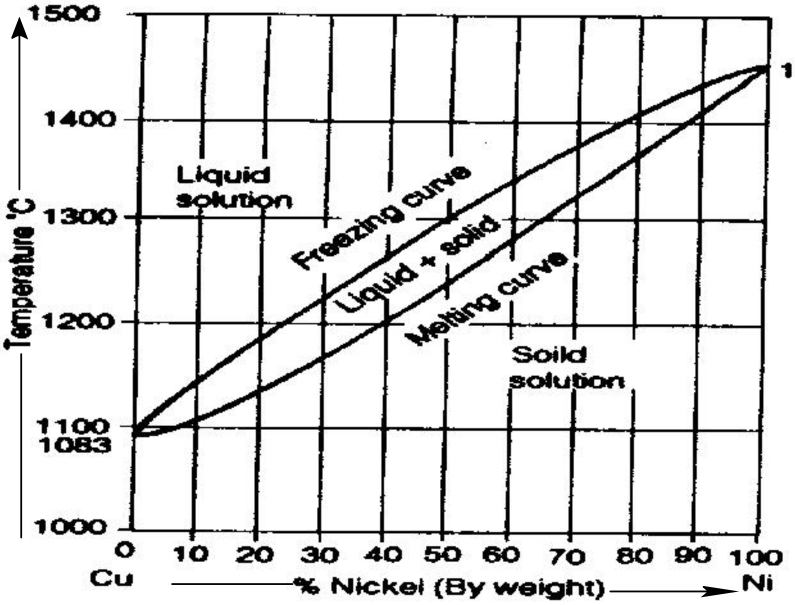


Fig. 2.7 Cu/Ni-a continuous series of solid solutions

When the atomic radii are nearly equal, complete solubility results and atom replacement may extend from 0 to 100%. For example, silver and lead both with a face-cent red cubic lattice form a single homogeneous solid solution over all ranges of composition. If atomic size is of somewhat different, the solubility is limited. For example, the brass alloy and there five phases. Examples of substitutional alloys include Cu/Ni, Cu/Au, K/Rb, K/Cs and Rb/Cs.

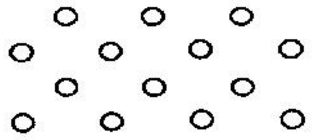


Fig. 2.8a Pure metal

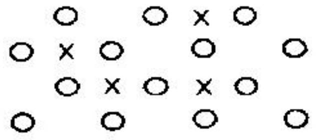


Fig. 2.8b Interstial alloy

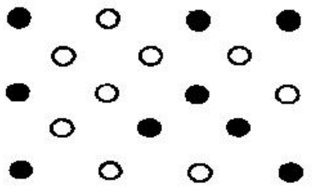


Fig. 2.9a Random substitutional alloy

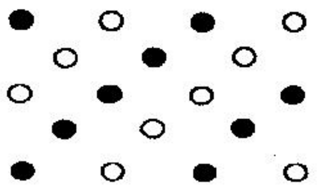


Fig. 2.9b Ordered substitutional alloy

In the Cu/Au case at temperatures above 450^0 C a disordered structure exits (Fig. 2.9a) but on slow cooling the ordered super-lattice may be formed (Fig. 2.9b). Only few metals form this type of continuous solid solution, and **Hume-Rothery** has shown that for complete miscibility certain rules should apply.

- The constituent metallic radii should not differ by more than 15%.
- Both metal must possess the same crystal lattice.
- The chemical properties, especially the number of valence electrons should be the same.

4. **Interstitial Alloys:** These are mixtures of a transition metal with a non-metallic element, in which atoms of certain lighter non-metallic element occupy some of metallic interstices in the metallic crystal lattice; the non-metallic element must be sufficiently small for the atoms to be thus accommodated.

Table 2.1

Elements	**H**	**B**	**C**	**N**
Atomic radius A^0	0.37	0.80	0.77	0.74

The main criterion for the formation of interstitial alloys is that the radius ratio of the smaller atom to larger atom should be in the range of 0.414-0.732. Hence hydrides, borides, carbides and nitrides of the transition elements constitute examples of the interstitial alloys. In addition, silicon phosphorus can form this type of alloy in some cases. These alloys are extremely hard, magnetic and have high m.p. and are of great technical importance, e.g. steel (Fe+C).

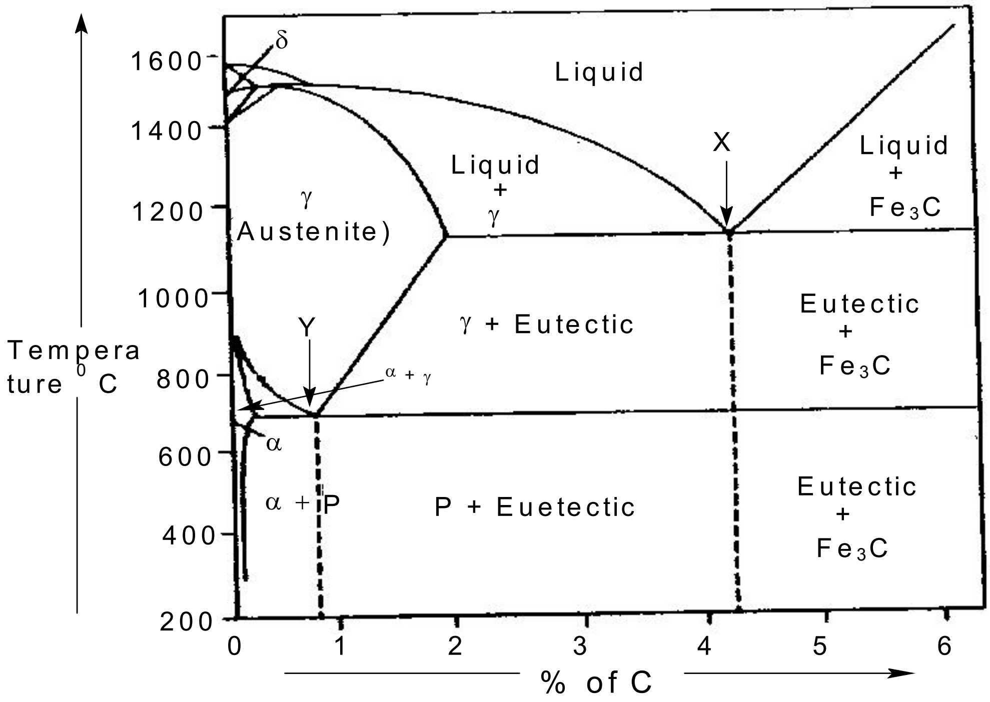


Fig. 2.10 Part of iron-carbon phase diagram (X=eutectic, Y=eutectoid, P=pearlite)

As shown in phase diagram of iron carbides, Fe exist in two allotropic forms; α-ferrite with bcc structure, stable up to 910^0 C and converted to γ-ferrite at higher temperature.

The upper part of the curve is of two solid are partly miscible and eutectic point **X** occur between γ-ferrite, iron carbide and liquid. Similar triple point occurs at **Y** in completely solid region is called eutectoid point. A solid with eutectoid composition (mix. of γ-ferrite + iron carbide) is called **'pearlite'**. This is a mixture, not a compound and the name pearlite refer to peal like appearance when examined under a microscope. The various regions α, β, γ, ʒ are different allotropic forms of Fe-C alloy.

Steel contains up to 2% carbon. The more carbon present, the harder and more brittle the alloy. When steel is heated can be rolled, bent or pressed into required shape. The properties of steel can be changed by annealing and tempering. Cast iron contain > 2% carbon, is hard and brittle. Heating cast iron does not produce solid solution, so cast iron cannot be worked mechanically and the liquid must be cast into required shape.

Bonding: There may be some degree of bonding between metal and non-metal which is indicated by:

- Expansion of the metallic lattice is shown by a slight increase in the metallic inter-atomic distance.
- Only transition metals with incompletely filled *d*-orbital form interstitial alloys, electrons may be donated by the interstitial atoms leaving them as cations and resulting in metallic type if cohesion.

Structure: If the radius ratio of non-metal to metal is less than 0.52, crystal lattice is cubic or hcp or bcc; if it is larger than 0.59, distortion of these lattices occur and stability of alloy decreases.

Composition: Composition may be stoichiometric (e.g. TiC, TiB_3, VN) or non-stoichiometric when non-metal is hydrogen (e.g. $TiH_{1.73}$, $PdH_{0.75}$, $PdH_{0.6}$).

Consider alloy of tin and lead. The radii differ by 8.0% and both are in the same group (IV), properties are similar. However structures are different, so they are partly miscible.

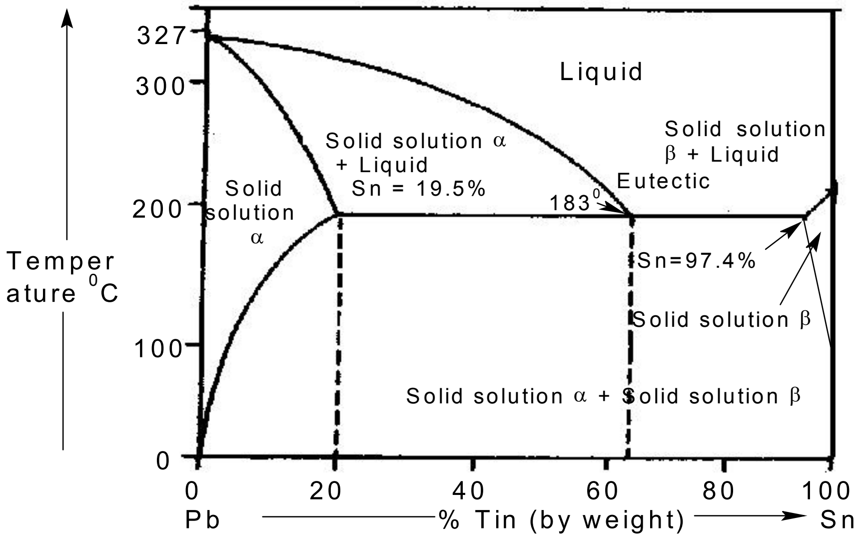


Fig. 2.11 Phase diagram for Sn/Pb alloy

There are two small areas labeled by α and β at the extreme left and right of phase diagram are of complete miscibility.

In other cases where limited range of solid solutions is formed, the tendency of the different metals to form compounds instead of solutions is important. For example, in the Cu/Zn (brass) alloys system. The metallic radii differ by only 7.0%, but they have different structure and different number of valence electrons. The atoms have strong tendency to form compounds and five different structures may be distinguished, as shown in table 2.2

Table 2.2

Phase	Zn Composition	Structure
α	0-35%	Random substituted solid solution of Cu in Zn
β	45-50%	Inter-metallic compounds of approximately stoichiometry CuZn. Stru. bcc.

γ	60-65%	Inter-metallic compounds of approximately stoichiometry Cu_5Zn_8 Stru. Complex cubic
ε	82-88%	Inter-metallic compounds of approximately stoichiometry $CuZn_3$ Stru. hcp.
η	97-100%	Random substituted solid solution of Cu in Zn

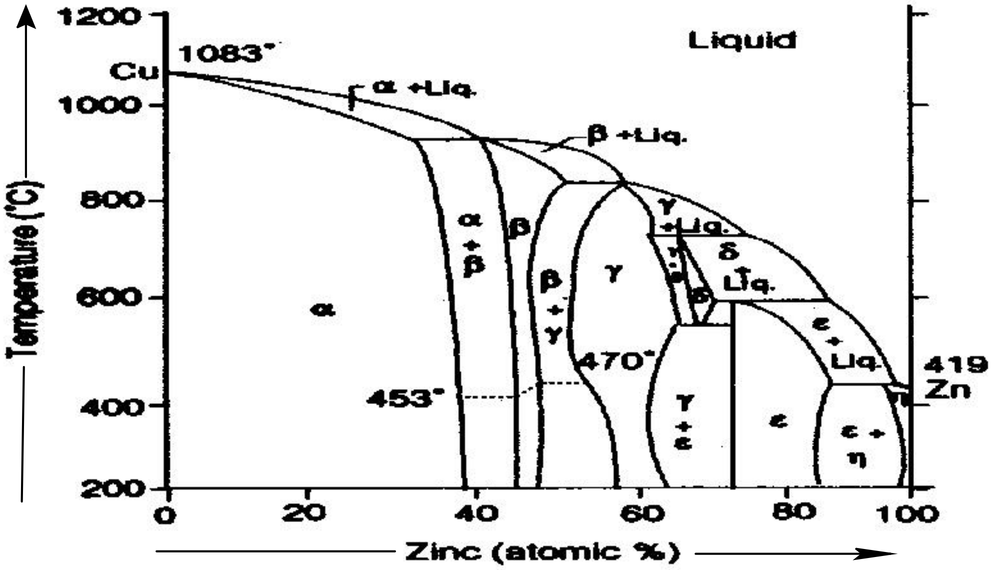


Fig. 2.12 Phase diagram for Cu/Zn alloy systems

The relation between the various phases is shown in the phase diagram and each phase represented by ideal formula.

5. **Inter-metallic Compounds:** When two metals form continuous range of solid solution, one or more intermediate phases may be formed. These phases, differing in crystal structure from the component metal are referred to as inter-metallic compounds.

   They are not true compounds, but have variable composition. Each compound may be assigned a formula. The two metals usually combine in stoichiometric proportions but do not follow any valence rules For example, Cu_5Zn, $Cu_{31}Sn_8$, Fe_3C, Pt_5Zn_{21}.

   Inter-metallic compounds differ structurally from the component metals and are stable over limited compositional range. **Laves** have been investigated these compounds and hence are referred as **'Laves phases'**. The compounds $MgZn_2$, Cu_2Mg, Na_2K, Li_2Ca etc. have constant radius ratio of ~ 1.25.

   For systematic study of these compounds component metals are divided into three classes.

   - Those of the sub group B with completed levels, such as Cu, Ag, Au, Zn, Cd, Hg (B-class).
   - Very strong electropositive metals such as Li, Na, K, Rb, Cs, Ca, Ba, Sr and rare earth (M-class).
   - Transition metal with partially filled d-levels (T-class).

   Thus binary system may be MM, MB, MT, TT, TB.

The inter-metallic compounds of the type TB, according to the Hume-Rothery have formulae and structures which are determined by the ratio of the number of valence electrons to the total number of atoms of both kinds are often referred to as the **‘electron compounds’**.

Large number of inter-metallic compounds has been found to exist. A careful study of these compounds establishing general relationship (rules) which may be summed up as follows.

a) Tamman’s rule:

- “Two metals capable of forming inter-metallic compounds never belong to the same sub-group of periodic table”. Exceptions are: KNa_2, Ca_3Mg_2, ZnMg.
- “A metal either combines with all the members of a sub-group of with none of them”.

In inter-metallic compound, the atoms of one metal are able to replace those of another in the crystal lattice and compounds generally formed between atoms of elements having low electron affinities. Inter-metallic compounds of Cu and Zn are having three phases with different composition and structure.

Table 2.3

β	45-50%	Inter-metallic compounds of approximately stoichiometry CuZn. Stru. bcc.
γ	60-65%	Inter-metallic compounds of approximately stoichiometry Cu_5Zn_8 Stru. Complex cubic
ε	82-88%	Inter-metallic compounds of approximately stoichiometry $CuZn_3$ Stru. hcp.

The existence of inter-metallic compounds in an alloy can be revealed by the X-ray analysis, thermal equilibrium diagram, hardness, electric conductivity etc.

b) Hume- Rothery rules: This rule is not a single one.

- **Succession of Hume-Rothery Phases:** “When the metal of higher valence (M’) is added to the metal of lower valence (M), there is formed a succession of inter-metallic phases”.

α	α + β	β	β + γ	γ	γ + ε	ε	ε + η	η

M M’

Fig. 2.13 Alloy Phases

The α and η are the phases at the two ends of the phase diagram are simply substituted solid solutions, one having same crystal structure as that of the metal M and other as that of the metal M’. The intermediate phases β, γ, ε are inter-metallic compounds characterized by melting point maxima in the phase diagram. The crystal structure of α is bcc, β-a complicated cubic structure and ε-phase has closed packed structure. For example Cu-Zn alloy.

- **Hume-Rothery’s Ratio rule: “**The factor governing the composition of the compounds is the ratio of valence electrons to the total number of the atoms of both kinds in the unit formula is constant for each type of phase”.

This ratio is called **Hume-Rothery’s ratio**.

$$\frac{\text{Total number of valency electrons}}{\text{Total number of atoms}} = \text{constant}$$

Thus, for the β–phases of system Cu–Zn, Cu–Al and Cu–Sn, considering copper, zinc, aluminium and tin to be 1–, 2–, 3– and 4– valent respectively, we have

$$CuZn\ (1+2)/2 = \frac{3}{2}$$

$$Cu_3Al\ (3+3)/4 = \frac{3}{2}$$

$$Cu_5Sn\ (5+4)/6 = \frac{3}{2}$$

Similarly, for the γ and ε–phases of the following system, the ratios are 21/13 and 7/4 respectively,

γ–Phases	ε–Phases
$Cu_5Zn_8 : (5+16)/13 = \frac{21}{13}$	$CuZn_3 : (1+6)/4 = \frac{7}{4}$
$Cu_9Al_4 : (9+12)/13 = \frac{21}{13}$	$Cu_3Sn : (3+4)/4 = \frac{7}{4}$
$Cu_{31}Sn_8 : (31+32)/39 = \frac{21}{13}$	$Ag_5Al_3 : (5+9)/8 = \frac{7}{4}$

Super structure: If the substitutional is such that, at a definite temperature, the distribution of the different atoms is regular and ordered throughout the crystal lattice the structure referred as a **'super lattice or super structure'**. Such solid solution is shown in fig. 2.14. Sometimes a disordered lattice may be converted into ordered by annealing at suitable temperatures. For example β-phase (Cu/Zn) system at 470^0 C, the lattice is disordered and when this is annealed at lower temperatures a super structure is formed. This is termed as an **'order-disorder transformation'**. Such a transformati -on reversible process and is independent on the temperature.

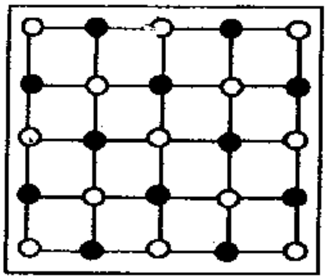


Fig. 2.14 Superstructure phase

Electron Compounds: Hume-Rothery rule shows that β and γ-phases compounds of transition metal of VIIIth group of the periodic table, it is found that these elements do not contribute any electrons to the alloy systems. Thus, for the β-phase compound CoAl, we have (0+3)/2 or 3/2 and for the γ-phase compound Fe_5Rh_{22} (0+42)/26 or 21/13. The above type of inter-metallic compounds where composition of each phase is determined by electron-to-atom ratio, are often referred to as the *electron compounds*.

Rules for formation of Alloys: Comparative studies of large number of alloys have led to the rules for the alloy formation formulated by **W. Hume-Rothery and others.** The rules have recognized two general types of criteria regarding alloy formation.

1. **Size factor:** "For substitutional alloy formation the size of constituents must be approximately the same, whereas one of the constituent of a interstitial alloy must

be small compared to the other". Thus size factor recognizes the importance of choosing two metals which can fit together in lattice structure. The atoms of minority categories (solute) may fit into the open space of the solvent lattice. The first case is known as substitutional alloy, while the second is called an interstitial alloy.

2. **Valency Factor:** This factor plays an important role. It is the electronic configuration of the atoms which determines why mixture of some elements form metallic alloys, whereas some form insulating alloy.

   Qualitatively it is found that alloys are formed from atoms of the middle of the electro-chemical series of the elements because there is always a tendency of the ions of the metallic state to polarize with respect to their neighbors and form an ionic compound instead of the metallic one. If the tendency is strong, no metallic alloy state can be formed, hence only elements from the middle of the series where there is little change in ionization potential from one atom to another atom can form successful alloy.

Some Important Alloys:

Alloys are subdivided into number of categories, but most important classification is ferrous versus non-ferrous alloys with respect to its industrial relation.

I. Ferrous Alloys: These are modified steel. Various types of steels are as follows.

a) **Ordinary steel:** It is an alloy of iron with carbon and comes in three general grades.

- Low carbon or mid steel (0.3% to 0.6% carbon).
- Medium steel (0.6% to 1.2% carbon).
- High carbon steel (1.2 to 1.9% carbon).

As proportion of carbon increases hardness and strength increases but ultimately this leads to brittleness as in the case of cast iron.

Alloy steels contain, beside iron and carbon one or more other elements to provide specific improved properties like mechanical, corrosion resistance, electrical conductivity or magnetic properties.

1) **Altered mechanical properties:** For this purpose Ti, V, Cr, Mn, Ni, Mo and W are added. Improved hardness, impact resistance and fatigue resistance result when one or more above listed elements are added. Molybdenum and tungsten, moreover impart temper retention at high temperature, a desirable property for high speed cutting tools.
2) **Improved corrosion resistance:** Ordinary steel is highly subject to rusting. For this Cr and Ni and occasionally lesser amounts of other elements such as Nb is added.

   There are many varieties of **'stainless steels'** but are all basically, iron-chromium-nickel alloys. A highly corrosion resistant iron-silicon alloy, **Duriron** containing 14% Si is used for pipes for corrosive material especially for acids. Its main defects are brittleness and lack of machinability.

b) **Vanadium steels:** Vanadium provides hardness, tensile strength and machining qualities, and find use for general engineering purpose. Addition of 0.1-2.5% of V gives excellent welding characteristics, 1-5% of V with Cr and W in steel finds use to make high speed tool. Vanadium steel finds use in high pressure boilers, gears and turbines.

c) **Chromium steels:** It is extremely hard, having increased strength, resistance to wear, oxidation and corrosion. Chromium steels find use in armor plate, ball bearings, high speed tool steels, grinding machinery, surgical instruments, etc.

d) **Cobalt steels:** Cobalt steels possessing up to 13% cobalt along with tungsten have been found to be hard, stainless and retain good mechanical properties at high temperatures. They used for high speed tools.

e) **Manganese steels:** Manganese is able to dissolve appreciable amount of iron. Manganese steels are very hard, have high tensile strength and finds use for railway points, for rock crushing and for helmets and arm our.

f) **Nickel steels:** Nickel steels are having strength, resistance to wear and withstand mechanical shock and strain. Up to 50% Ni yields steels for gears, steering compounds, transmission parts, drills and arm our plate. Invar (36% Ni) has ~ zero co-efficient of thermal expansion.

g) **Tungsten and molybdenum steels:** Tungsten and molybdenum steels find use in manufacture of dies for drawing wires, etc. and making high speed cutting or drilling tools.

II. Non-ferrous Alloys: There are more type's non-ferrous alloys than ferrous alloys. We can list only a few more important types of commercial alloys.

a) **Brass and bronze:** These are of copper with zinc and tin respectively. They are manufactured because of their desirable properties of colour, machinability, and relative corrosion resistance. They possess physical properties which are required for certain musical instruments (bells, cymbals-□□□□□). Special brasses and bronzes such as phosphorus bronze, which has desirable elastic properties and is thus used to make non-sparking tools. Aluminium bronze is used as the pigment in aluminium paint.

b) **Low melting alloys:** Solder is alloys of tin and lead which have extended melting range to permit them to work as semi-solid. Wood's metal with 50% Pb + 25% Sn + 12.5% Cd + 12.5% Bi have below 100^0 C melting point are used for plug in fire protection.

c) **Type metal alloys:** These are low-melting alloys, but also have a property of expansion upon freezing, a necessary property if sharp type face is to be obtained (80% Pb + 20%Sb).

d) **Light metal alloys:** Pure aluminium is too soft and fragile for many uses as for example, in aero plane. Therefore, a large group of Al alloys has been developed; most of these are combination with Mg, also a light metal. Typical alloys include the following:

- Magnalium (90% Al, 10% Mg)
- Duralumin (94% Al, 4%Cu, small amount of Mg, Mn, Si)
- Dow metal (93.8% Mg, 6% Al, 0.2% Mn)

e) **Fusible alloys:** Fusible alloys are generally composed of Bi, Pb and Sn. They melt at comparatively low temperatures, below the m. p. of tin. They also have property of expanding on cooling and used in making plugs.

f) **Non-corroding alloys:** In addition to stainless steels, there are non-ferrous alloys that have desirable corrosion resistance.
  - German silver (46% Cu, 34% Zn, 20% Ni)
  - Monel metal (30% Cu, 70% Ni, small amounts of Mn, Fe)

Coinage and jewellery metal: These are usually mixtures of Ag and Au or either Ag or Au with Cu. Pure gold, 24 carat gold, is too soft for use in coins and most jewellery. Lesser carat ratings indicate increasing amounts of silver added to gold to increase its hardness.

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