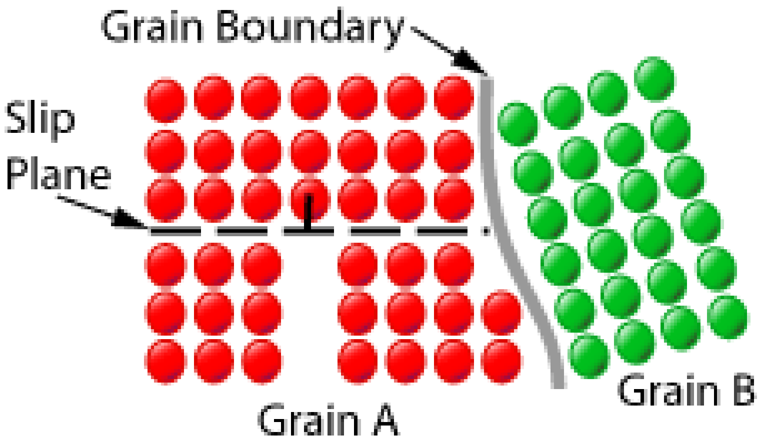
Сегодня: суббота,
30 апреля 2016 г.

Use of English for professional training

Workshop 3



Fundamentals of Metal Forming Processes: Strengthening of Metals

Associated Professor of National Research Tomsk Polytechnic University, Kuprekova E.I.

Part 1. Mechanisms of Strengthening

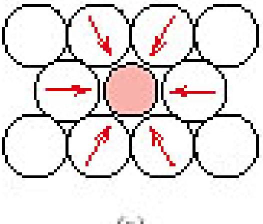
- The ability of a metal to plastically deform depends on the ability of dislocations to move
- Reducing or inhibiting mobility of dislocations enhances mechanical strength

These can be used for increasing the material strength, but ductility may be lost.

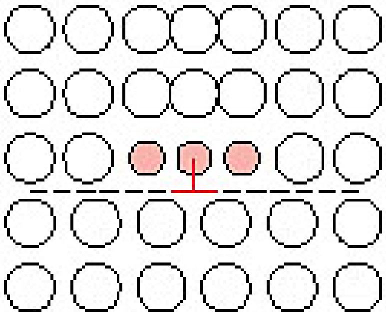
When Slip is Inhibited?

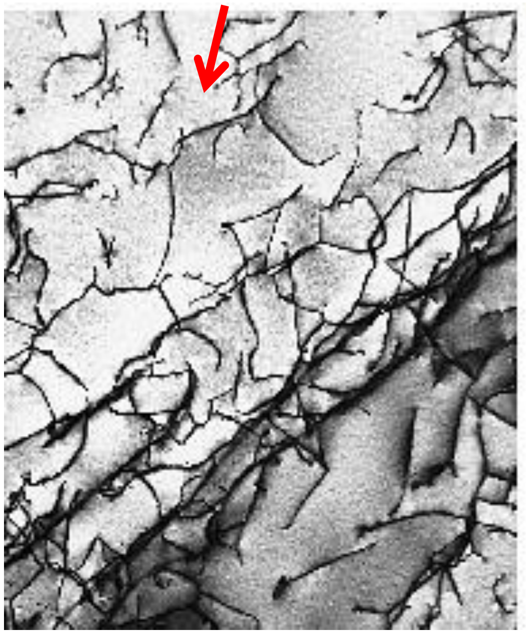
Dislocation motion may be inhibited by:

Other dislocations (entangling)
Grain boundaries
Point defect (solution hardening)
Other phases -Precipitates



(a)





Dislocation forest

Strengthening of Metals

There are 4 major ways to strengthen metals, and all work because they make dislocation motion more difficult. They also reduce the ductility:

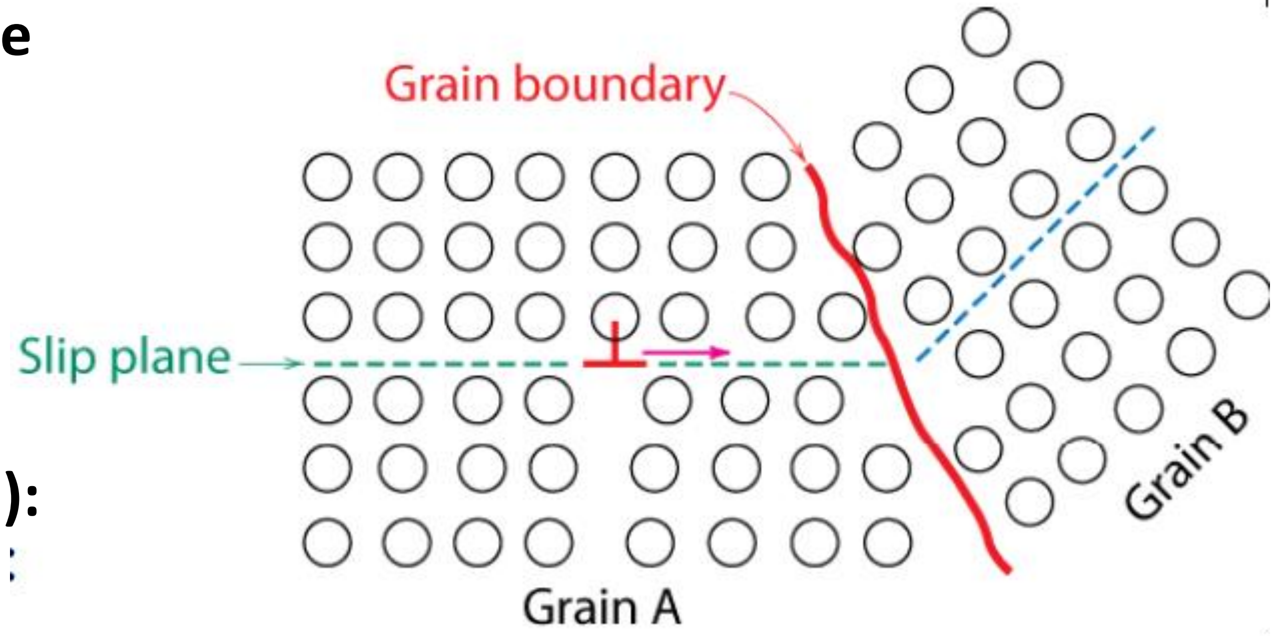
1. **Cold work (*Strain Hardening*)**
2. **Reduce grain size (*Strengthening by Grain Size Reduction*)**
3. **Add other elements in solid solution (*Solid Solution Strengthening*)**
4. **Add second phase particles (*Precipitation or Age Hardening*)**

- **These mechanisms may be combined.**
- **For example, the world's strongest structural material (with some ductility) is steel piano wire. It combines all four strengthening mechanisms, and can have a yield strength of 500,000 psi. One wire, 0.1"in diameter, can hold up a 4,000 lb Ford Explorer.**

Strategies for Strengthening:

1. Reduce Grain Size

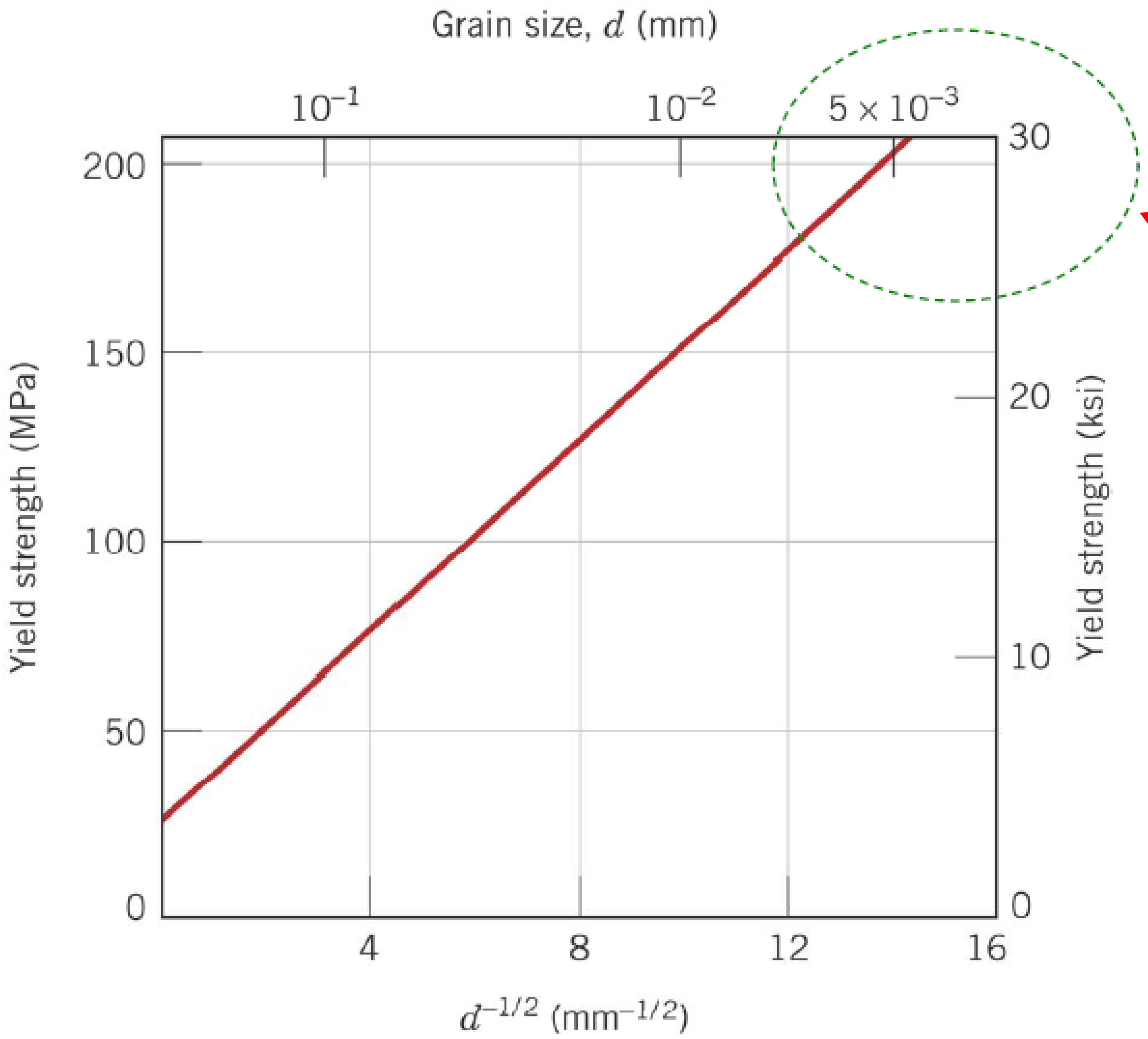
- Grain boundaries are barriers to slip.
- Barrier "strength" increases with increasing angle of misorientation.
- Smaller grain size (d): more barriers to slip.



- Hall-Petch Equation:

$$\sigma_{yield} = \sigma_0 + \frac{k}{\sqrt{d}}$$

1. Reduce Grain Size



Very difficult to synthesize polycrystalline materials with d < 100 nm

$$\sigma_{yield} = \sigma_0 + \frac{k}{\sqrt{d}}$$

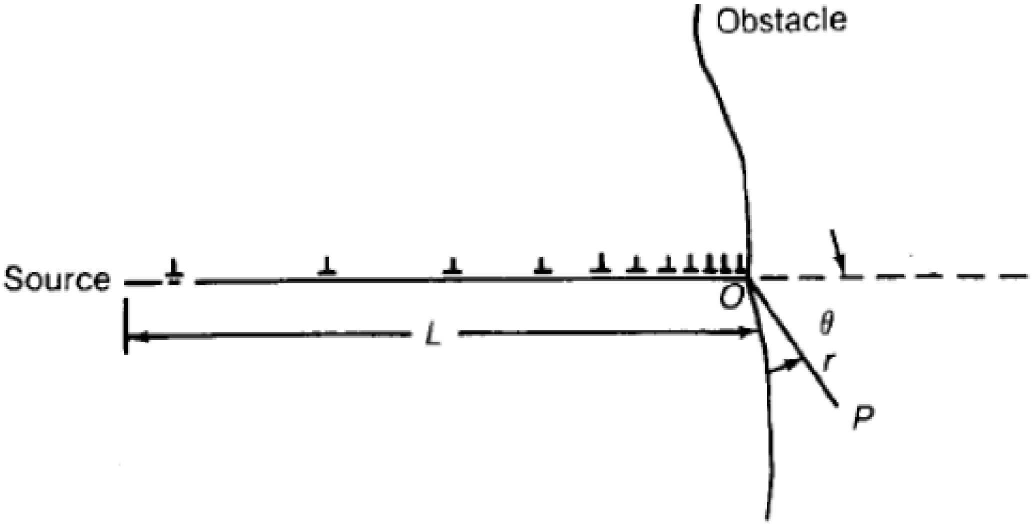
1. Reduce Grain Size

Primary mechanism for strengthening by grain boundaries…

$$\sigma = \frac{3}{2}\sqrt{\frac{L}{r}}\tau_s \sin\theta \cos\frac{\theta}{2}$$

The maximum value of σ occurs at θ = 1/3 or θ = 70.50/ For this situation

$$\sigma = \frac{2}{\sqrt{3}}\sqrt{\frac{L}{r}}\tau_s$$



Dislocation-up at an obstacle

The shear stress acting in the plane OP is given by

$$\tau = \beta\tau_s\sqrt{\frac{L}{r}}$$

Where β is an orientation-dependent factor which is close to unity

Task 1. Review Questions

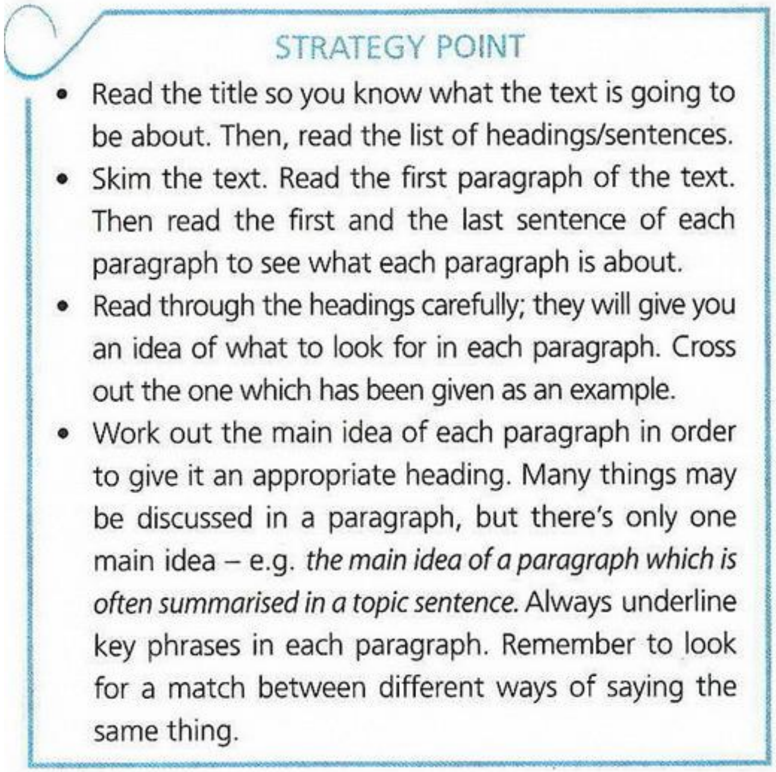
Work with a partner. Discuss the following questions

1. ***Why did it take society so long to develop metals.***
2. ***Define an alloy.***
3. ***Why do metals break even though they are not stressed beyond their elastic limit? What conditions cause this type of failure?***
4. ***What effect on tensile strength does stretching copper have?***
5. ***What is effect of grain boundaries on strength of metals?***
6. ***Are grain boundaries desirable for high temperature structural application? Give reasons for your answer.***
7. ***How can a metallic system be made into an amorphous material?***

Part 2.Reading

1. In pairs, look at the title of the article "Solid solutions" and the headings in the box, and discuss what you think the text might be about

A. Hume Rothery rules
B. Relative size factor
C. The solubility of lead
D. Relative valence factor
E. Substitutional solid solutions
F. Chemical affinity factor
G. Interstitial solid solutions
H. Crystal structure factor
I. Intermetallic compounds
J. Types of solid solutions



STRATEGY POINT

- Read the title so you know what the text is going to be about. Then, read the list of headings/sentences.
- Skim the text. Read the first paragraph of the text. Then read the first and the last sentence of each paragraph to see what each paragraph is about.
- Read through the headings carefully; they will give you an idea of what to look for in each paragraph. Cross out the one which has been given as an example.
- Work out the main idea of each paragraph in order to give it an appropriate heading. Many things may be discussed in a paragraph, but there's only one main idea – e.g. *the main idea of a paragraph which is often summarised in a topic sentence.* Always underline key phrases in each paragraph. Remember to look for a match between different ways of saying the same thing.

2. Read the article “Solid solutions” (Appendix 1) and choose the most suitable heading (A-J) for each paragraph (1-9). There is one extra heading which is not needed. Which words in each paragraph helped you decide?

⇒ Vocabulary Practice

3. In pairs, look at the highlighted words in the text and try to explain them

liquid state, homogeneous, abundant, brass, substitutional, crystal lattice, disordered, ordered solid solution, solvent, restricted, affinity, holes, compounds

⇒ Text Analysis

4. In pairs, discuss the following questions

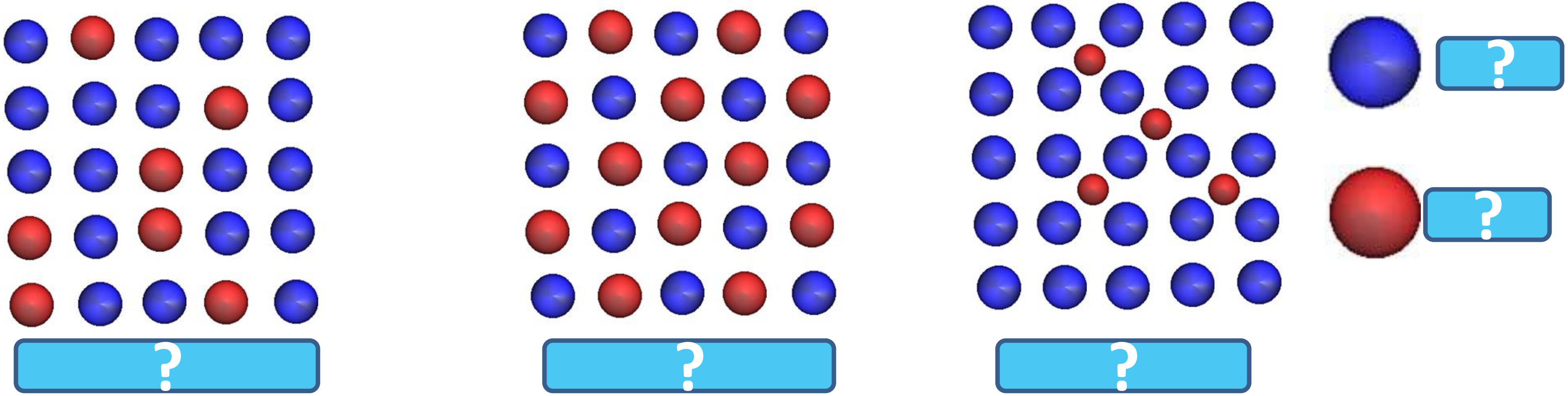
1. What is a solid solution?
2. How many types of solid solutions are there? Give examples for each of them?
3. What are Hume-Rothery rules?
4. If two metals have very different electronegetavity will they form a solid solution?
5. How does valence of an element affect the solid solubility?
6. What is an ideal solution?

Solid Solutions

When two metals are mixed together they form an alloy if one metal is soluble in the other one in solid state. Therefore, an alloy is a solid solution of two or more metals.

Primarily there are two types of solid solutions –

- **Substitutional – Solute atoms occupy the regular lattice sites of the parent metal (solvent). Substitutional solid solutions can be random (Cu-Ni) or ordered (Cu-Au).**
- **Interstitial – Solute atoms occupy the interstitial positions (Steel – C solute atoms in Fe).**



Choose the most suitable title: Solvent, Solute, Interstitial, Random substitutional, Ordered substitutional

Hume-Rothery Rules

Formation of substitutional solid solutions between two metals is governed by a set of rules known as

Hume-Rothery rules

- **Size difference between the atoms of solute and the parent metal should be less than 15%.**
- **The electronegetivity difference between the metals should be small (minimum chemical affinity to each other).**
- **The solubility of a metal with higher valence in a solvent of**

  lower valence is more compared to the reverse situation e.g. Zn is much more soluble in Cu than Cu in Zn.
- **For complete solubility over the entire range of compositions the crystal structures of the solute and the solvent must be the same.**

Ordering in Solid solutions

✓As stated before substitutional solid solutions can be either ordered or random. This depends on a thermodynamic parameter called enthalpy of mixing, ΔH_{mix}

$$\Delta G_{mix} = \Delta H_{mix} - T \Delta S_{mix}$$

ΔG_{mix} is the Gibbs free energy change and ΔS_{mix} entropy of mixing. For an ideal solution $\Delta H_{mix} = 0$.

✓ If $\Delta H_{mix} > 0$, formation of like bonds (A-A or B-B) is preferred in a solid solution between metals A and B. This known as clustering.

✓If $\Delta H_{mix} < 0$, unlike bonds (A-B) are preferred. This leads to ordering which may exist over short range or long range (at lower temperatures).

Intermediate Phases

✓ As the name suggest intermediate structures formed between two metals are neither the parent metals nor like an alloy.

Intermetallic compounds

If two elements have high difference in electronegetivity, they tend to from a system called intermetallic compound. Intermetallic compounds like MgSe, PbSe, Mg2Si, Cu2S are cubic whereas NiAs, MnSe, CuSn are hexagonal.

Electron or Hume Rothery phases

These compounds have wide range of solubility and occur at certain values of valence electrons to atom ratio such as 3:2 (CuZn), 21:13 (Cu_5Zn_8), 7:4 ($CuZn_3$).

Intermediate Phases

Laves phase

Laves phases have a general formula of AB_2, for example $MgCu_2$ (cubic), $MgZn_2$ (hexagonal), $MgNi_2$ (hexagonal)

Sigma phase

Sigma phase has a very complex crystal structure and is very brittle. This phase can act as a source of embrittlement in some alloys such as steels.

Metal carbides and nitrides

Metals which have high chemical affinity for carbon and nitrogen form carbides and nitrides such as VC, NbC, VN, NbN, TiC, TiN. They can act as source of hardening in many alloys.

Home task

Task 1. **Write a report about solid solutions.**

Questions that need to be addressed:

1. **What is a solid solution?**
2. **How many types of solid solutions are there?**
3. **What is clustering?**
4. **What is ordering?**
5. **What is an intermetallic compound?**
6. **What is Hume-Rothery phase?**
7. **What is Laves phase?**
8. **What is sigma phase?**
9. **What kind of metals form carbides?**

Home task

1. The atomic radius of Cu is 0.128 nm and electronegativity is 1.8. What is the probability of lead, Pb (atomic radius 0.175 nm, electronegativity 1.6) and zinc, Zn (atomic radius 0.133 nm, electronegativity 1.7) forming solid solution with copper?

2. Predict the relative degree of solid solubility of the following elements in Fe (r = 0.124 nm, electronegativity 1.7). Ni (atomic radius, r = 0.125 nm, electronegativity 1.8), Cr (r = 0.125 nm, electronegativity 1.6), Ti (r = 0.147 nm, electronegativity 1.3)

Appendix 1

SOLID SOLUTIONS

A solid solution is formed when two metals are completely soluble in liquid state and also completely soluble in solid state. In other words, when homogeneous mixtures of two or more kinds of atoms (of metals) occur in the solid state, they are known as solid solutions. The more abundant atomic form is referred as solvent and the less abundant atomic form is referred as solute. For example sterling silver (92.5 percent silver and the remainder copper) is a solid solution of silver and copper. In this case silver atoms are solvent atoms whereas copper atoms are solute atoms. Another example is brass. Brass is a solid solution of copper (64 percent) and zinc (36 percent). In this case copper atoms are solvent atoms whereas zinc atoms are solute atoms.

1.

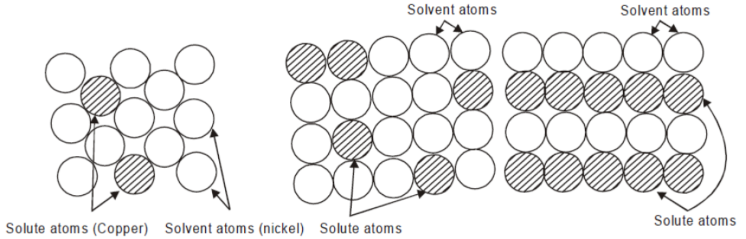
Solid solutions are of two types. They are
(*a*) Substitutional solid solutions.
(*b*) Interstitial solid solutions.

2.

If the atoms of the solvent or parent metal are replaced in the crystal lattice by atoms of the solute metal then the solid solution is known as substitutional solid solution.
For example, copper atoms may substitute for nickel atoms without disturbing the F.C.C structure of nickel (Fig. 1*a*). In the substitutional solid solutions, the substitution can be either disordered or ordered.
Figure 1*b* shows disordered substitutional solid solution. Here the solute atoms have substituted disorderly for the solvent atoms on their lattice site. Fig. 1*c* shows an ordered substitutional solid solution. Here the solute atoms have substituted in an orderly manner for the solvent atoms on their lattice site.

3.

By studying a number of alloy systems, Hume Rothery formulated certain rules which govern the formation of substitutional solid solutions. These are:



(*a*) Substitutional solid solution (*b*) Disordered substitutional (*c*) Ordered substitutional

Fig. 1 Solid solutions

4.

For complete solid solubility, the two elements should have the same type of crystal structure i.e., both elements should have either F.C.C. or B.C.C. or H.C.P. structure.

5.

As the size (atomic radii) difference between two elements increases, the solid solubility becomes more restricted. For extensive solid solubility the difference in atomic radii of two elements should be less than about 15 percent. If the relative size factor is more than 15 percent, solid solubility is limited. For example, both silver and lead have F.C.C. structure and the relative size factor is about 20 percent. Therefore the solubility of lead in solid silver is about 1.5 percent and the solubility of silver in solid lead is about 0.1 percent. Copper and nickel are completely soluble in each other in all proportions. They have the same type of crystal structure (F.C.C.) and differ in atomic radii by about 2 percent.

6.

Solid solubility is favoured when the two metals have lesser chemical affinity. If the chemical affinity of the two metals is greater than greater is the tendency towards compound formation. Generally, if the two metals are separated in the periodic table widely then they possess greater chemical affinity and are very likely to form some type of compound instead of solid solution.

7.

It is found that a metal of lower valence tends to dissolve more of a metal of higher valence than vice versa. For example in aluminium-nickel alloy system, nickel (lower valance) dissolves 5 percent aluminium but aluminium (higher valence) dissolves only 0.04 percent nickel.

8.

In interstitial solid solutions, the solute atom does not displace a solvent atom, but rather it enters one of the holes or interstices between the solvent atoms. An excellent example is iron-carbon system which is shown in Fig. 2

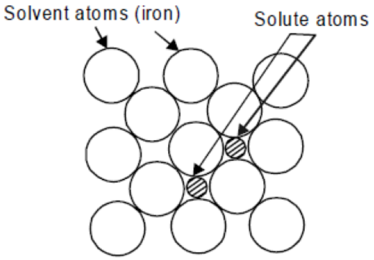


Fig. 2 Interstitial solid solutions

9.

Intermetallic compounds are generally formed when one metal (for example magnesium) has chemical properties which are strongly metallic and the other metal (for example antimony, tin or bismuth) has chemical properties which are only weakly metallic. Examples of intermetallic compounds are Mg_2Sn, Mg_2Pb, Mg_3Sb_2 and $Mg_3 Bi_2$. These intermetallic compounds have higher melting point than either of the parent metal. This higher melting point indicates the high strength of the chemical bond in intermetallic compounds.