Alloys and intermetallics

Alloy

Commercial metals may contain detectable amounts of foreign atoms. It is difficult and expensive to produce metals of absolute purity due to:

- ❑Incomplete removal during refining, S in steel.
- ❑Accidental/unavoidable addition during production of metal, like Sulphur in steel, H in Al.
- ❑Intentional addition of an element to remove their impurities. Ex: Mn in steel.
- ❑Absorption during service, S observed by Ni alloy from furnace atmosphere.
- ❑ *Intentional addition of an element or elements to increase desirable properties like mechanical, physical and chemical properties. Such intestinally added elements are called alloying elements and the product is an alloy.*

An alloy is a material having **typical properties expected of a metal** but is not a pure metallic element. An alloy Is a metallic solid formed by an **intimate combination of a metal and one, or more than one metal and/or non-metal, but has metallic properties.** The metallic atoms must dominate in its composition, and the metallic bonds in its crystal structure.

The structure of solidified alloy depending upon the nature of atoms:

A) Indifferent to each other: they behave as if belonging to same species. They get mixed up together so thoroughly that the alloy is homogeneous even up to the atomic scale, form random S.S.

B) ***Attract on another (electrochemically similar):*** if attracted and if electrochemically similar, form ordered S.S. form regular alternate pattern.

C) ***Repel each other (electrochemically differ):*** form partials ionic bond, formation of inter-metallic compound. If highly electronegative, a true chemical compound is formed.

Alloy structure

- Solid solution
  - Substitutional
  - Interstitial
- Intermediate alloy phases
  - Intermetallic compound
  - Interstitial compound

In many alloy systems, crystal structures or phases are found that are different from those of the elementary components (pure metals). ***intermediate phases***.

If it crystalses over the range of compositions → ***Solid solution***.

New crystal structure occurs with simple whole number fixed ratios of the component atoms → ***Intermetallic compound***

EX: Cu (FCC) + Zn (HCP) → Brass (BCC structure exist over the range of composition, so it is not compound but a solid solution.) (47-50 wt.% Zn)

Ex: β' phase in brass, Cu-Al2 in Al-Cu system, TiAl3 in Al-Ti system.

Ex: When carbon is added to iron, Fe_3C observed, which having fixed C%, 6.67. called interstitial intermediate compound.

Solid solution (S.S.)

When the liquid solution of two metals crystallizes, and if a solid of only single crystal structure forms, then a S.S. has formed.
Solubility limit: upper limit of solute atom goes into the solvent. C in iron, Zn-Cu,
Cu-Ni do not exhibits solubility limit. (100% solubility)

Substitutional solid solution: when atom of the solute element substitute the atoms of solvent.
Ex: Cu-Ni SS

Ordered solid solution: is a substitutional solid solution in which the atoms arranged themselves in Preferred manner, two species are arranged in some regular alternating pattern. Ex: Cu-Ni, β' brass, Au-Ag, Cu-Au

Ordered solid solution is expressed as

$$E_{XY} < \frac{1}{2}(E_{XX} + E_{YY})$$

Energy
Of unlike bond

Long range order structure

Disordered/random solid solution: substitution of atoms has taken place at random. β brass,

Interstitial S.S.

Solute atoms are much smaller than the solvent atoms, and thus occupy randomly interstitial space in between the solvent atoms in the crystal lattice of the solvent. Increase misfit and lattice strain, increasing strain energy causes upper limit.

Element	B	C	N	O	H
Atomic radius (A°)	0.97	0.77	0.71	0.60	0.46

Hume Rothery's rules for substitutional solid solution:

This rules deal with formation of continuous/extended/complete solid solubility.

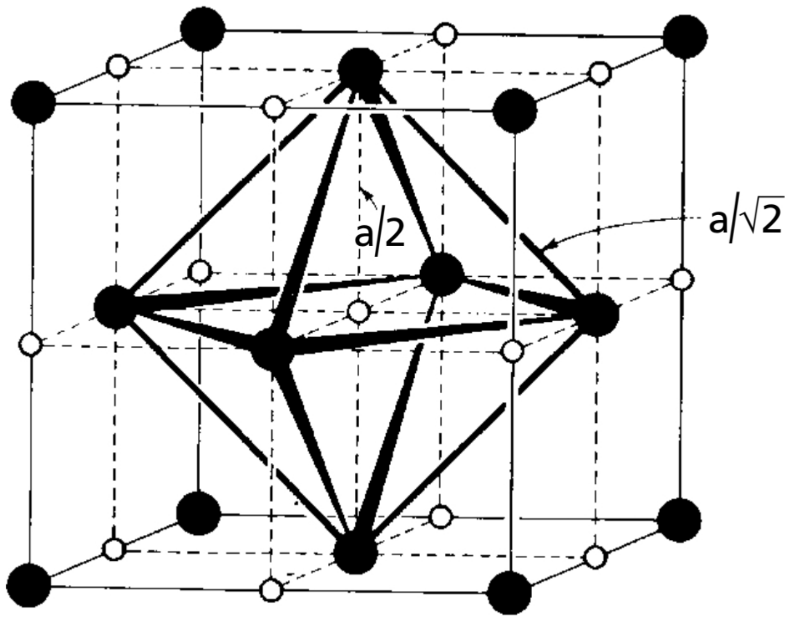
A) Atomic-size factor :

B) Electrochemical factor:

C) Crystal structure factor

D) Relative valency factor

Interstitials solubility

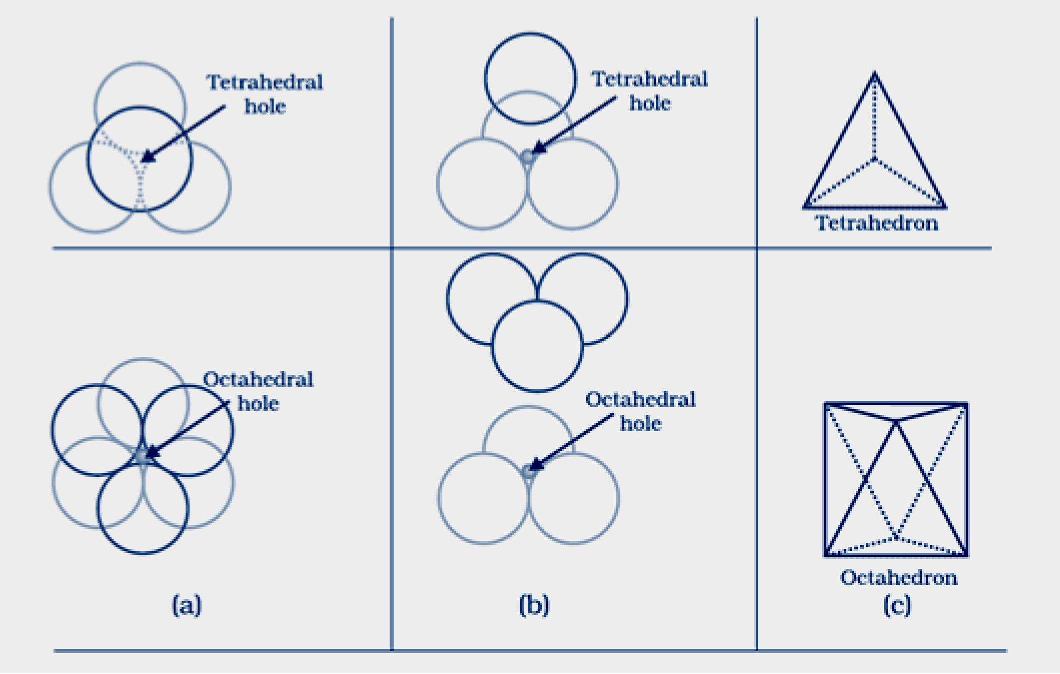


In ϒ iron, octahedral void can accommodate : 0.52 A
Whereas tetrahedral can fit an atom of size 0.28A
C, N sit in octahedral void.

Assignment 03

In α iron,
octahedral void can accommodate : 0.19A
Whereas tetrahedral can fit an atom of size 0.36A
Carbon goes in __________ void. Why??

Explain why, at the same temperature of 727 C (A1), ϒ iron-fe can dissolve up to 0.77 wt%, where as α iron is able to dissolve carbon up to 0.025 wt %.



Intermetallic

Intermetallic compound, **any of a class of substances composed of definite proportions of two or more elemental metals**, The crystal structures and the properties of intermetallic compounds often differ markedly from those of their constituents.

- A compound of two/more metals that has a distinct chemical formula, It appears an intermediate phase in a phase diagram that exist over a narrow range of compositions.
- Most of the alloy system don't show complete solid solubility, when amount of solute element is more than the solid solubility limit, a second phase also appears apart from the primary solid solution.
  Second phase which forms is an intermediate phase.
- It is a phase formed at intermediate composition between the two primary components.
- Crystal structure is differ from both the primary components.
- Some of these intermediate phases have a fixed composition are called intermetallic compound.

In many binary alloy systems, when the chemical affinity of elements is high, their mutual solubility become limited. Intermetallic compound/phase formed. It is combination of +ve and –ve charge of valence elements.
Ex: NaCl, H_2O, H_2SO_4. when compound is formed the elements loose their individual properties and identity to a large extent.

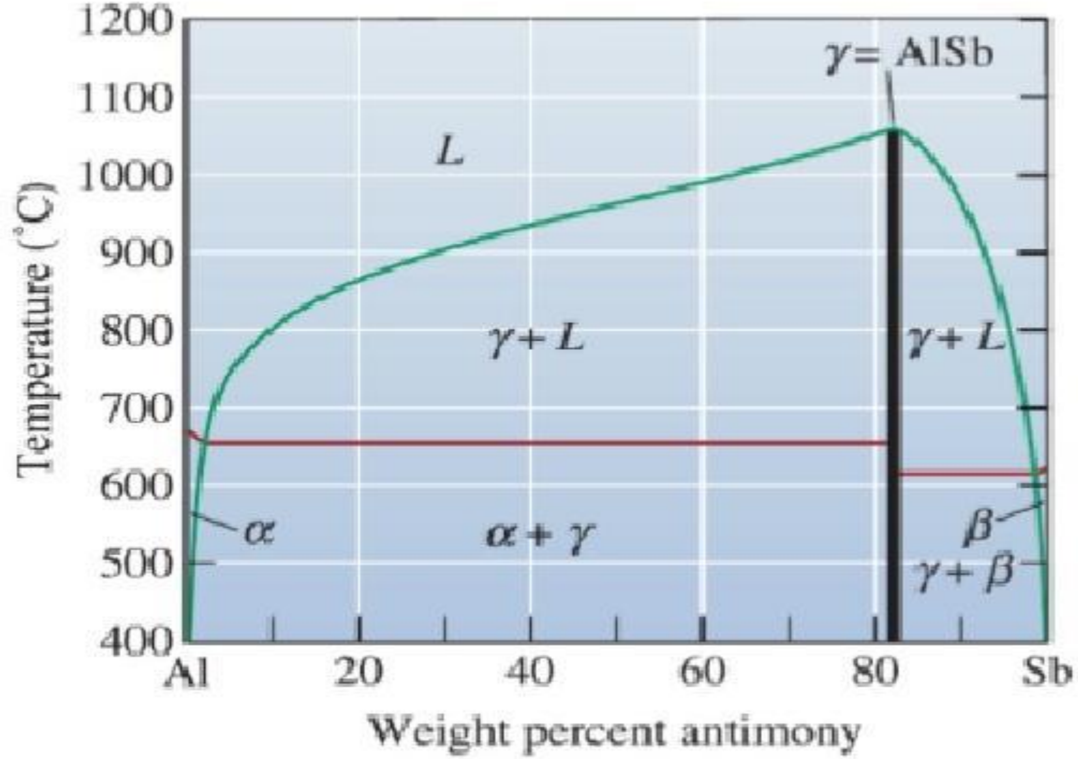
Elements with similar electronegativity tend to form alloy but elements with large electronegativity difference tend to have More ionic bonds or intermetallics.

Intermetallic have different crystal structure and properties than parent components.
It is very hard and brittle, high melting temperature. It is used in dispersed materials in dispersion hardening.

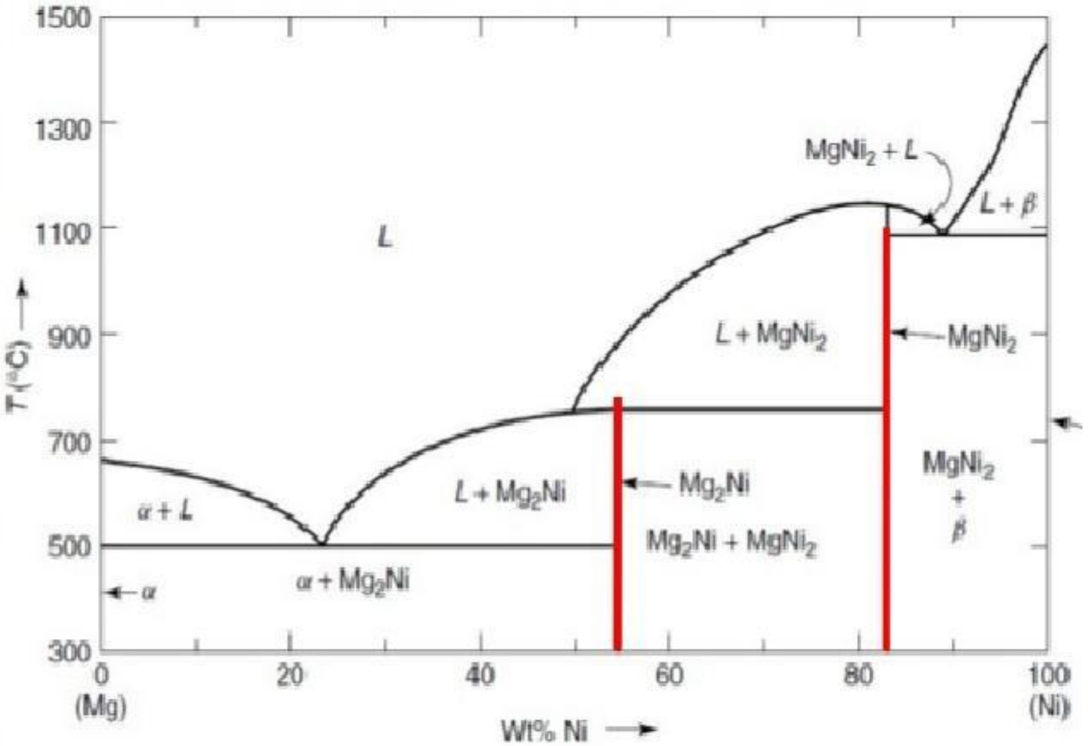
Stoichiometric intermetallic: have fixed composition and represented by vertical line in phase diagram.
Ex: Au_2Pb, AlSb, $MoSi_2$, Mg_2Pb, $MgNi_2$.

Non-stoichiometric intermetallic: have a range of compositions, intermediate phases.
γ phase in Mo-Rh system, β' phase in brass, Cu-Al_2 in Al-Cu system, $TiAl_3$ in Al-Ti system.

Stoichiometric intermetallic compound

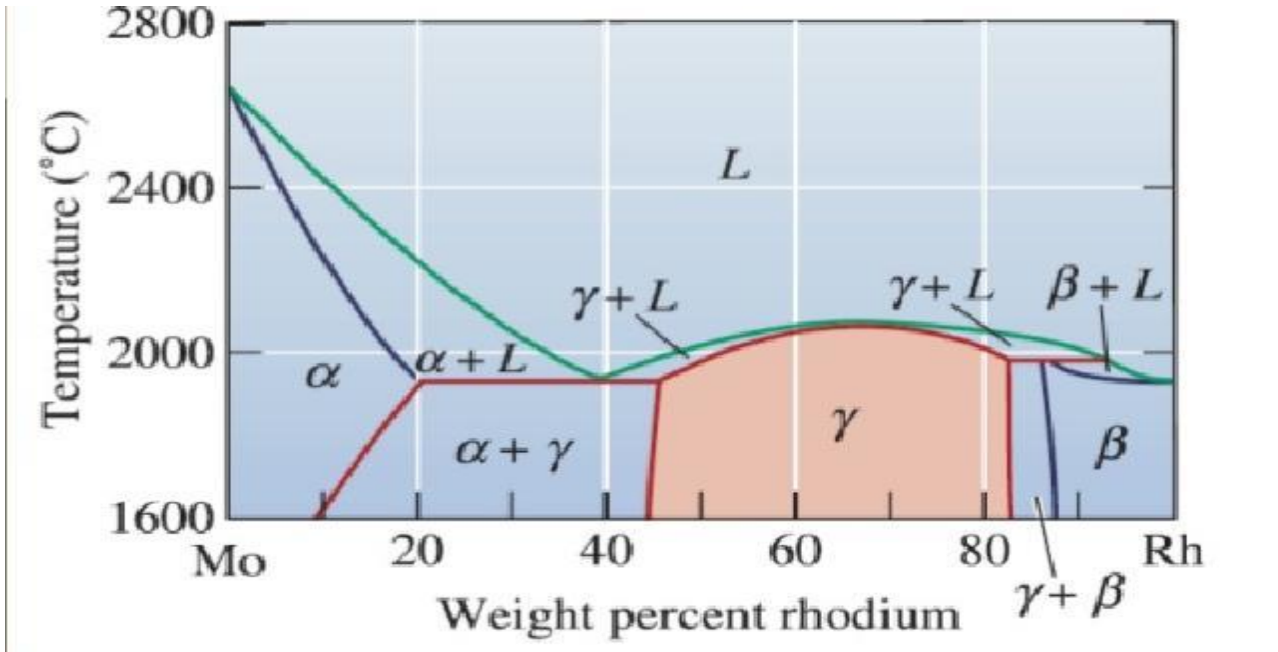


Aluminum-antimony phase diagram includes a stoichiometric intermetallic compound γ

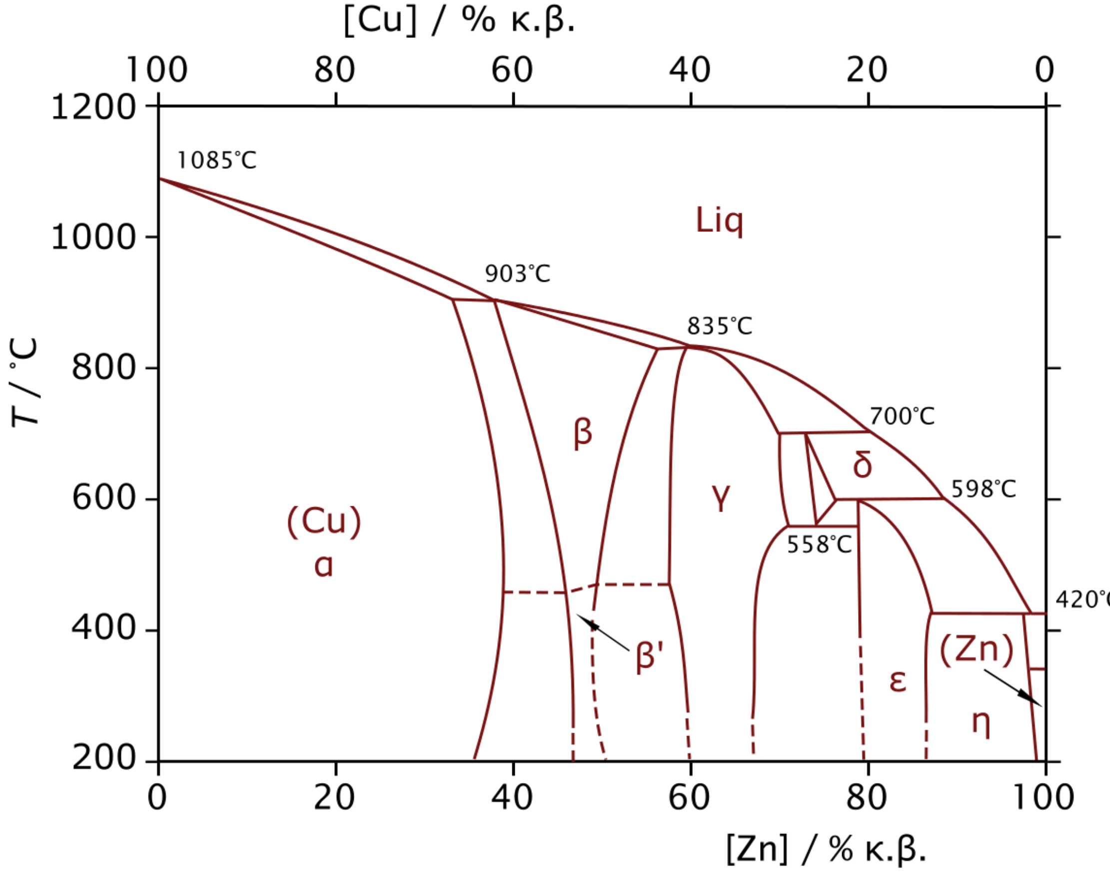


Magnesium - Lead phase diagram includes a stoichiometric intermetallic compound γ. 8

Nonstoichiometric intermetallic compound



The molybdenum-rhodium phase diagram includes a nonstoichiometric intermetallic compound γ.

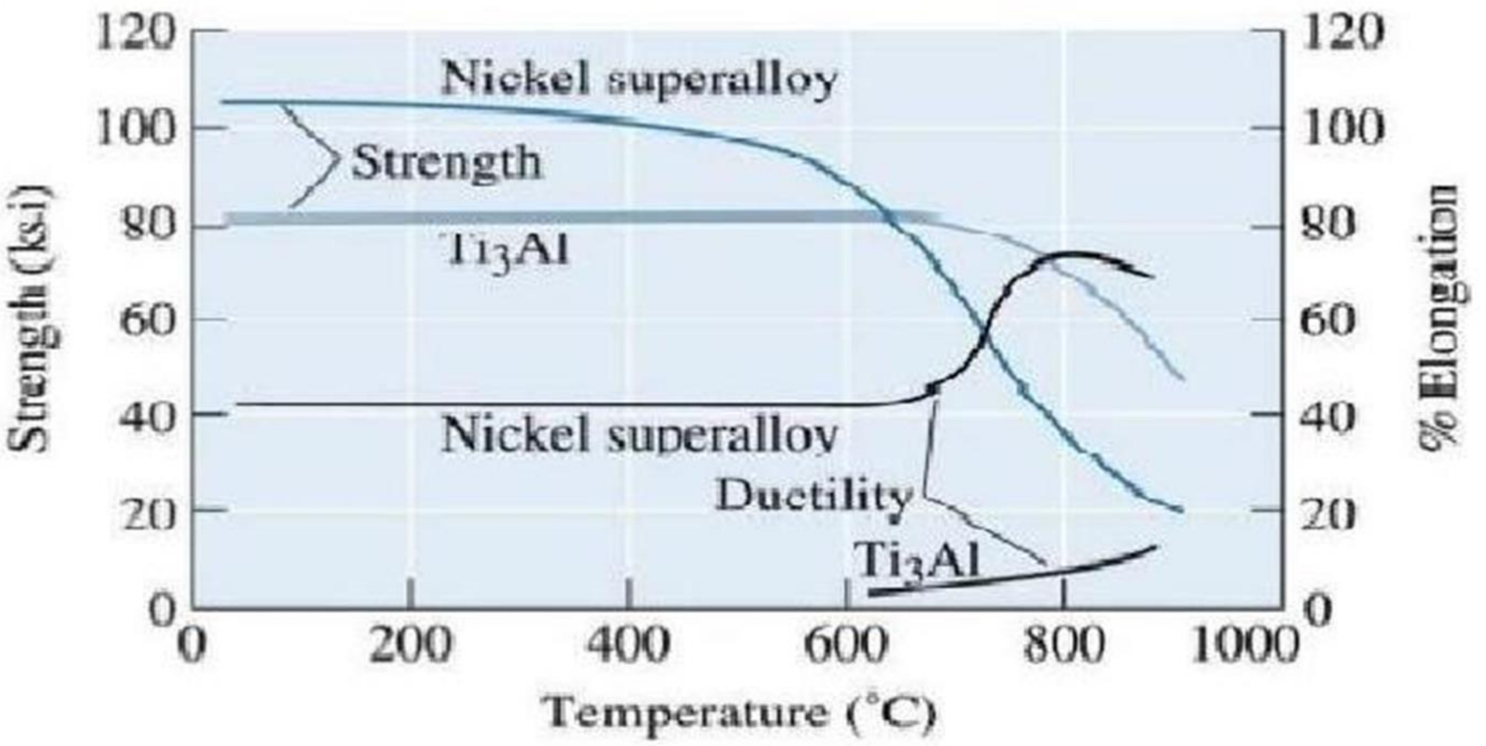


The Copper - Zinc Phase diagram, containing more than 30% Zn, a second phase β’ forms because of the limited solubility of zinc in copper

Properties of some Intermetallic compounds

Intermetallic Compound	Crystal Structure	Melting Temperature (°C)	Density $\left(\frac{g}{cm^3}\right)$	Young's Modulus (GPa)
FeAl	Ordered BCC	1250–1400	5.6	263
NiAl	Ordered FCC (B2)*	1640	5.9	206
Ni_3Al	Ordered FCC ($L1_2$)*	1390	7.5	337
TiAl	Ordered tetragonal ($L1_0$)*	1460	3.8	94
Ti_3Al	Ordered HCP	1600	4.2	210
$MoSi_2$	Tetragonal	2020	6.31	430

- Properties of some Intermetallic compounds
- STRENGTH AND DUCTILITY



The strength and ductility of the intermetallic compound Ti_3Al compared with that of a conventional nickel superalloy. The Ti_3A maintains strength to higher temperatures longer than does the nickel superalloy.

Properties & uses:

Copper Aluminide (CuAl2)

Precipitation of the nonstoichiometric intermetallic copper aluminide $CuAl_2$ causes strengthening in a number of important aluminium alloys. Precipitation hardening – by forming θ ($CuAl_2$) phase in α matrix, gives high strength and toughness.

- Properties:

1- High strength (505 - 520 MPa).
2- Good creep strength at high temp.
3- High toughness at cryogenic temp.
4- Good machinability

-APPLICATION

1- Fuel Tanks
2- Pistons, rivets for aircraft constructions : Al_2CuMg 22

Al-Mg-Si Alloys (Mg_2Si)

Mg and Si are added in balanced amount to form Mg_2Si

- Properties

1- Medium-strength structural alloys (215 -245 Mpa).

-Applications

1 - Car bodies
2- Electric trains
3- Structural Components
4- Satellite dish
5- Large water pipes
6- Aircraft, Automotive

TiAl and Ni3Al (Nickel base superalloys)

- Properties

1- TiAl and Ni3Al possess good combinations of high-temperature mechanical properties and oxidation resistance up to approximately 650 - 960°C.

2- Good Toughness and Corrosion resistance.

- Applications:

1-Aircrafts, space vehicles, rocket engines

2- Industrial gas turbines

3- Nuclear reactors, submarines

4- Steam power plants, petrochemical equipment

5- Combustion Engine Exhaust Valves

6-Submarines

Molybdenum disilicide (MoSi2)

- This material is used for making heating elements for high temperature furnaces
- At high temperatures (1000 to 1600°C), MoSi2 shows outstanding oxidation resistance.
- At low temperatures (500°C and below), MoSi2 is brittle

Al-Mg-Si Alloys (Mg2Si)

Mg and Si are added in balanced amount to form Mg2Si

- Properties

1- Medium-strength structural alloys (215 -245 Mpa).

-Applications

1 - Car bodies
2- Electric trains
3- Structural Components
4- Satellite dish
5- Large water pipes
6- Aircraft, Automotive