Class: `1st Stage
Subject: Engineering Materials
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Thermal Equilibrium Diagrams (Phase Diagrams)

Equilibrium may be defined as a state of balance of stability. When a metal solidifies, equilibrium will occur under conditions of **slow cooling** where the reduction in temperature is small in relation to the time elapsed (gone). To achieve equilibrium it would be necessary, at every stage of cooling, to give the alloy elements **time to diffuse** (mix through on another) which would lead to a state that each grain of metal would have the same composition throughout. Complete diffusion seldom takes place in casting because solidification usually takes place before diffusion is complete.

There are a number of different types of thermal equilibrium diagrams

1. Two metals completely soluble in each other in both liquid and solid states.
2. Two metals completely soluble in each other in the liquid but not in the solid state (**Eutectic alloy**).
3. Two metals completely soluble in each other in the liquid and partially soluble in the solid state.
4. Iron / Carbon equilibrium diagram.

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1 Two metals completely soluble in each other in both liquid and solid states

Instead of dealing with several different cooling curves for any alloy, a quicker graph has been created using the various arrest points of all the alloys. When these points are marked on a graph and joined up we get a thermal equilibrium diagram which looks like this in figure below.

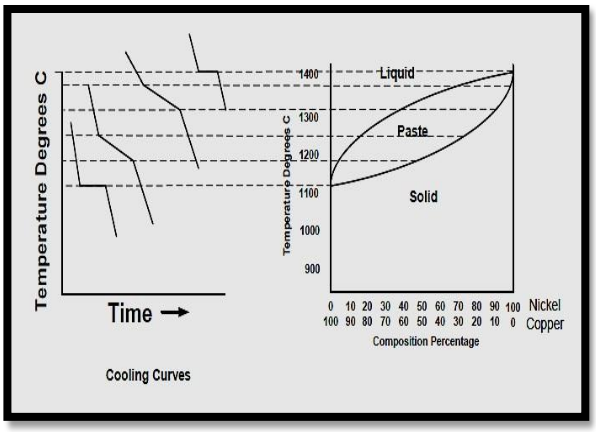

Figure 1. Creating a thermal equilibrium diagram.

As you can see there are three areas the **liquid state**, the **solid state** and the **pasty state** (consists of a solid phase and a liquid phase). A very important point to note is that the line joining all the points where the liquid begins to solidify is known as the **Liquidus line** while the line joining all the points where solidification is just complete is known as the **Solidus line**. If we want to find out what temperature **60%** Copper is fully solidifies at in an alloy of Copper and Nickel. Firstly we need the thermal equilibrium diagram for the alloy of Copper and Tin. This is the thermal equilibrium diagram for the alloy of Copper and Nickel. In order to find what temperature **60%** copper solidifies at we simply draw a

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vertical line from **60%** copper until it hits the solidus line and at this is the point where **60%** Copper has fully solidified.

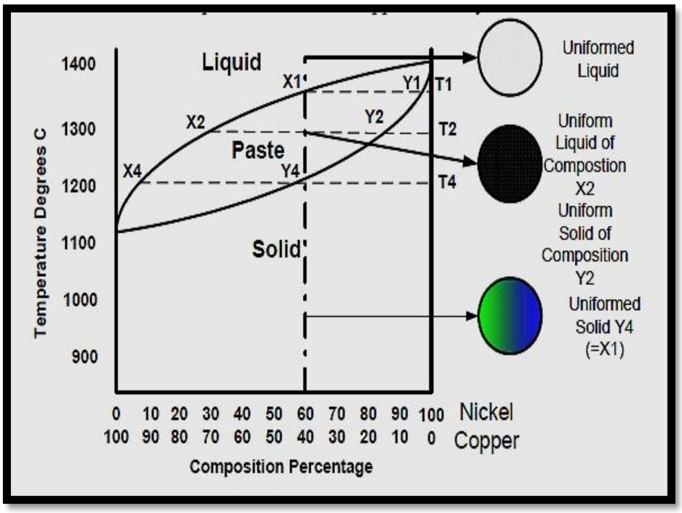

Figure 2. Nickel-Copper thermal equilibrium diagram.

2. Two metals completely soluble in each other in the liquid but not in the solid state

(Eutectic alloy)

An eutectic is an alloy of lowest melting point in that alloy system and is formed when two different solid phases separate simultaneously at constant temperature from a single liquid phase (i.e. changing from a solid to a liquid at a constant temperature).

The solid solution equilibrium diagram discussed was formed by two metals being totally soluble in both the liquid and solid states. A Eutectic equilibrium diagram results when the two metals are soluble in the liquid state but insoluble in the solid state. In the liquid state the two metals are soluble in each other but when cooling is complete, the grain of the solid alloy consist of two distinguishable metals which can be seen under a microscope to be like a layer of one metal on top of a layer of the other metal. This state is completely different where the cooled solid grains look just like one metal when viewed under a microscope. In order to fully understand this type of alloy combination we will look at the (**CadmiumBismuth**) eutectic thermal equilibrium diagram. Cadmium and Bismuth are completely soluble in the liquid state, but are completely insoluble in the solid state.

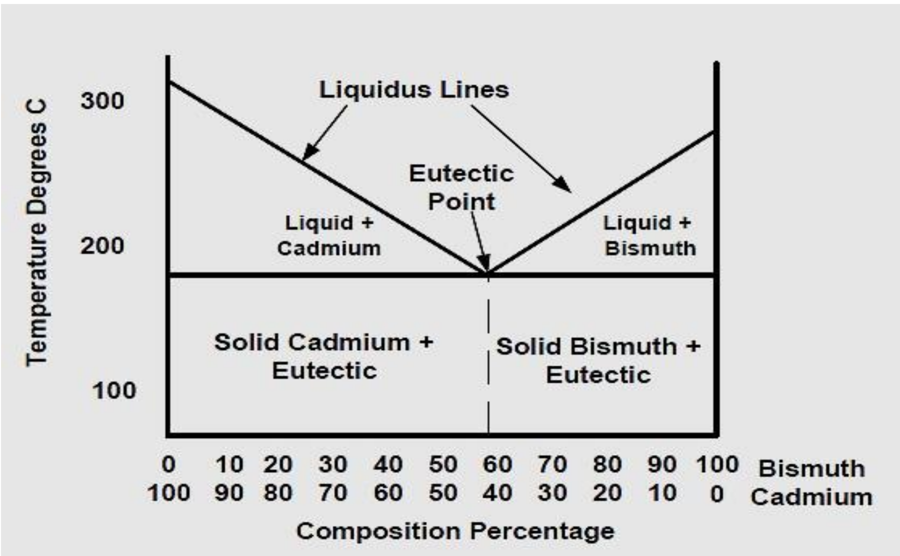

Figure 1. Bismuth-Cadmium (Eutectic Alloy).

The first and most noticeable point on this diagram is the **Eutectic point**. The eutectic point as can be seen above is a point in the diagram where the liquid alloy changes to a solid without going through a

pasty state. This is the lowest melting point of any composition for the alloy.

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As you would accept everything above the liquidus line is in the liquid state and in this state the two metals are totally soluble in each other. In the eutectic point region, there is only the eutectic composition alloy. If you look at **100%** Cadmium you will see that there is a large amount of solid Cadmium while this decreases in the alloys found nearer to the eutectic. The same applies for Bismuth. Therefore we can say that as the composition of the alloy moves away from the eutectic composition, grains of either Cadmium or Bismuth appear in the eutectic matrix.

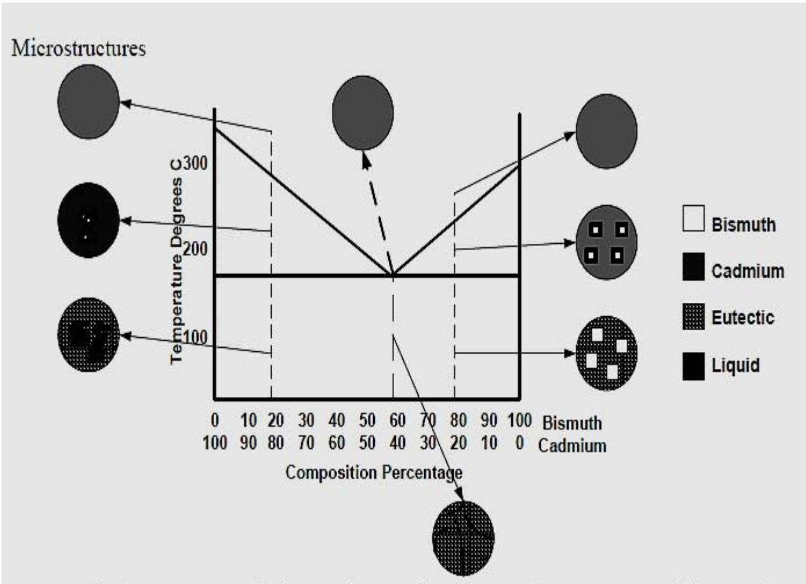

Figure 2. Bismuth-Cadmium (Eutectic Alloy).

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An examination at **80%** Cadmium and **20%** Bismuth. As the temperature falls crystal nuclei of pure cadmium begin to form. The temperature cuts the liquidus line at **(80/20)%** and the other phase boundary is the **100%** Cadmium ordinate. Dendrites of cadmium are deposited and the remaining liquid becomes increasingly richer in bismuth. Therefore the composition of the liquid moves to the right. As the temperature decreases more cadmium deposition takes place. The growth of Cadmium dendrites and consequent enriching of the remaining liquid is Bismuth.

The changing properties depending on metal composition are shown in figure below.

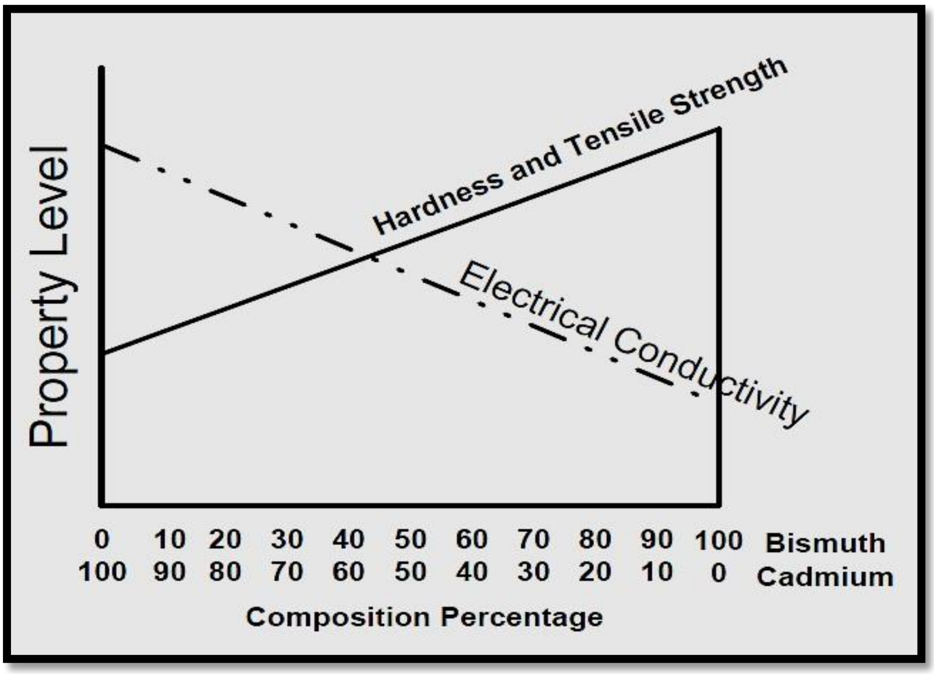

Figure 3. Metal Properties.