

M37- Introduction to Phase Equilibria and Microstructure

Aim

To observe the etched microstructures of alloys that underwent different heat treatment procedures and then explaining the visible morphological features using concept of phase equilibria, any deviations from it and the phase diagram.

Introduction

One of the most important tools that material scientists and engineers deal with during alloy synthesis is phase diagrams. A phase diagram is a graphical representation of the different phases present in the alloy, when in thermodynamic equilibrium, as function of two conditions such as temperature and composition. Furthermore, it can be used in conjunction to the lever rule to determine the weight composition of each phase during phase equilibria. This information can further be used to determine the volume fraction of each phase.

However, this is not indicative of the distribution and morphology of the phases present as this is totally dependent on the kinetics and mechanics of phase transformation during different heat treatments. The different rates of cooling and additional heat treatments can cause affect the diffusion of the constituents during the solidification process and result in different microstructures and morphological features. Understanding of these microstructures is important because they are responsible for the physical properties of the material.

Results

X2 (Cu/4% Sn - as cast)

The different morphological features present in this image are coring, grain boundaries and porosity which are marked by blue, red and green circles respectively in figure 1. There is a high concentration of porosities and coring throughout the surface. The size of the porosity varies from approximately 20 to 200 micrometres in diameter whilst the coring are approximately 5 to 20 micrometres in diameter. On the top of the grain boundary, the crystal has an golden colour whilst below the grain boundary it is orangish.

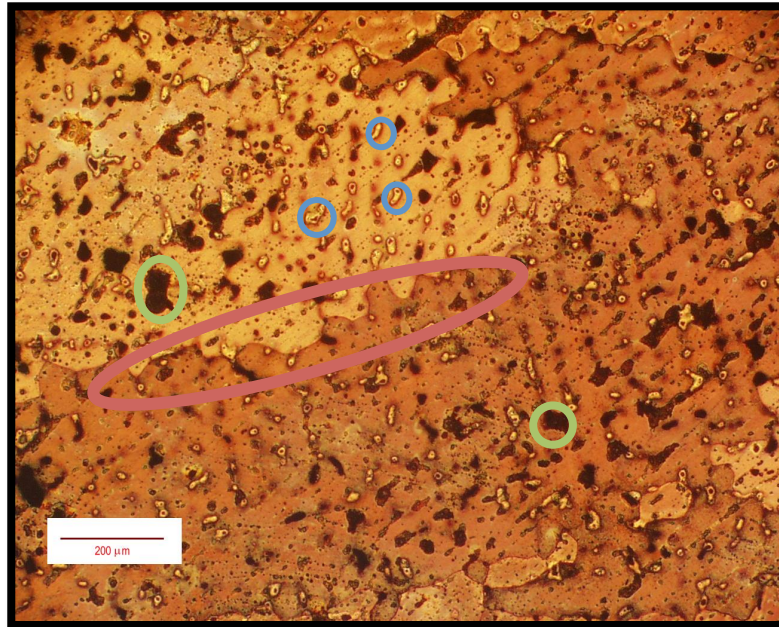


Figure 1 Etched Cu/4% Sn alloy achieved by casting under a magnification of $\times 50$

X3 (Cu/4% Sn - homogenised)

This etched surface presents two morphological features- porosity and cracks. The porosity and crack is marked by blue and red circles respectively in figure 2. The diameter of the porosity of 5 to 50 micrometres. The length of the cracks are 30 to 150 micrometres in length.

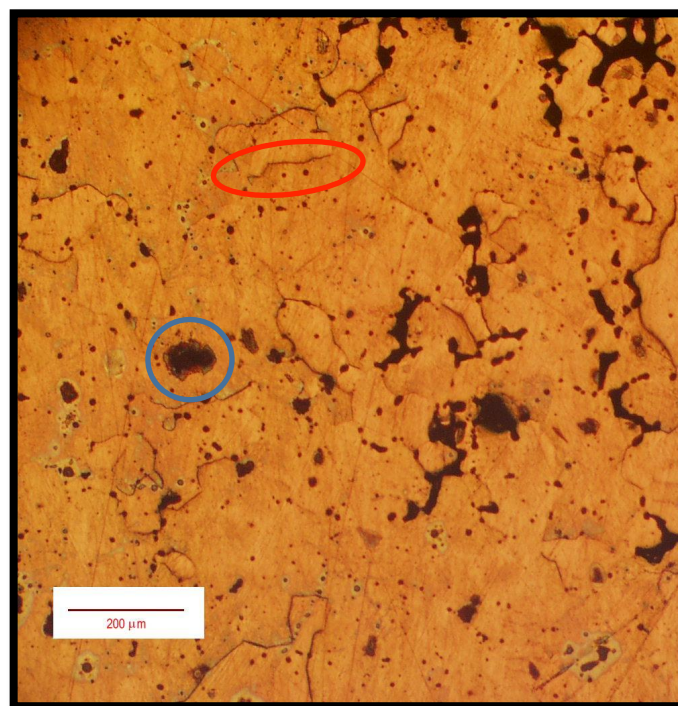


Figure 2 Etched surface of Cu/4% Sn (cast and homogenized) observed under a magnification of $50\times$

There is a low density of porosity.

X5 (Cu-8.4% P, eutectic composition)

The contrast in shades observed due to instant freezing of the liquid. Other features observed are cracks and porosities marked by blue and red circle respectively in figure 3. The cracks are arranged in parallel sets and are 40 to 100 micrometres in length. The diameters of the



Figure 3 Etched surface of Cu-8.4% P magnified by a factor of $\times 50$

porosity vary in 30-100 micrometres. This is magnified by a factor of 50.

In figure 4, the contrasting two colour represents two different phases. The golden and white phase are α and β phases respectively. The families of lamellae differ in interlamellar spacings. The families in the top left corner, in the middle and in the right bottom corner have interlamellar spacing of 2, 10 and 1 micrometres.

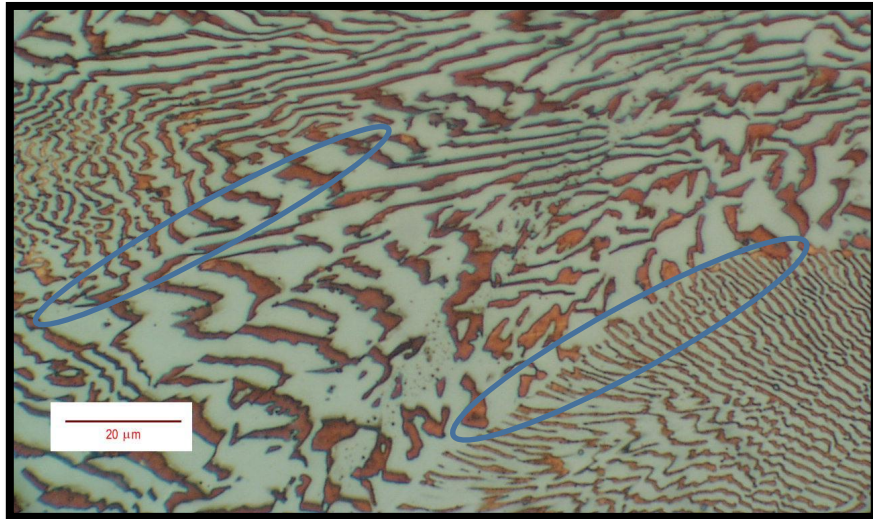


Figure 4 Etched surface of Cu-8.4% P magnified by a factor of $\times 200$

X6 (Cu-4.5% P, hypoeutectic):

In figure 5, there is a different contrast of colours in the etched surface. The purple is pro-eutectic α phase and the other feature present is porosity. The porosity sizes vary from 10 to 100 micrometres.

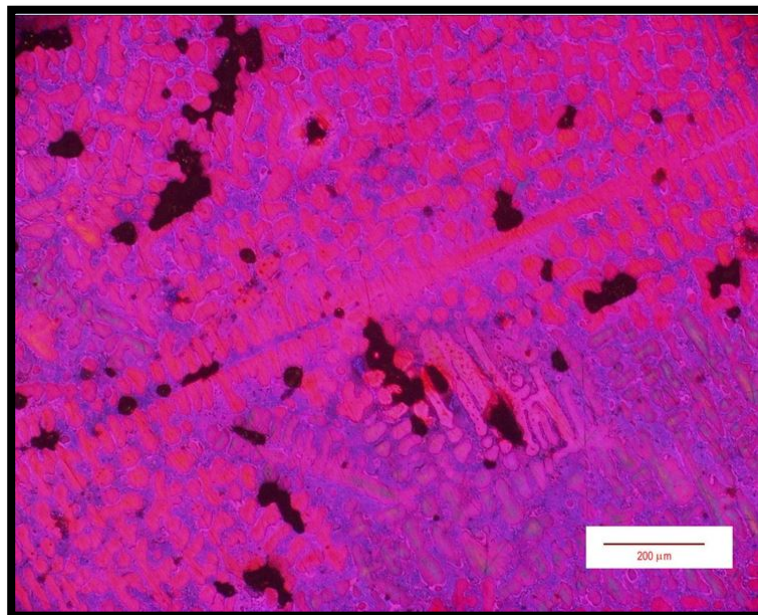


Figure 5 Etched surfaces of Cu-4.5% P under magnification by a factor of $\times 50$

In figure 6, there are two different phases. The pink component is pro-eutectic α phase and the remaining part of the β phase. The diameters of the islands of the α phase varies between 40-60



Figure 6 Figure 5 Etched surfaces of Cu-4.5% P under magnification by a factor of $\times 200$

micrometres.

X7 (Cu-10.5% P, hypereutectic):



Figure 7 Etched Cu-10.5% P, hypereutectic viewed under microscope

X8 (Cu-37% Zn, as cast):

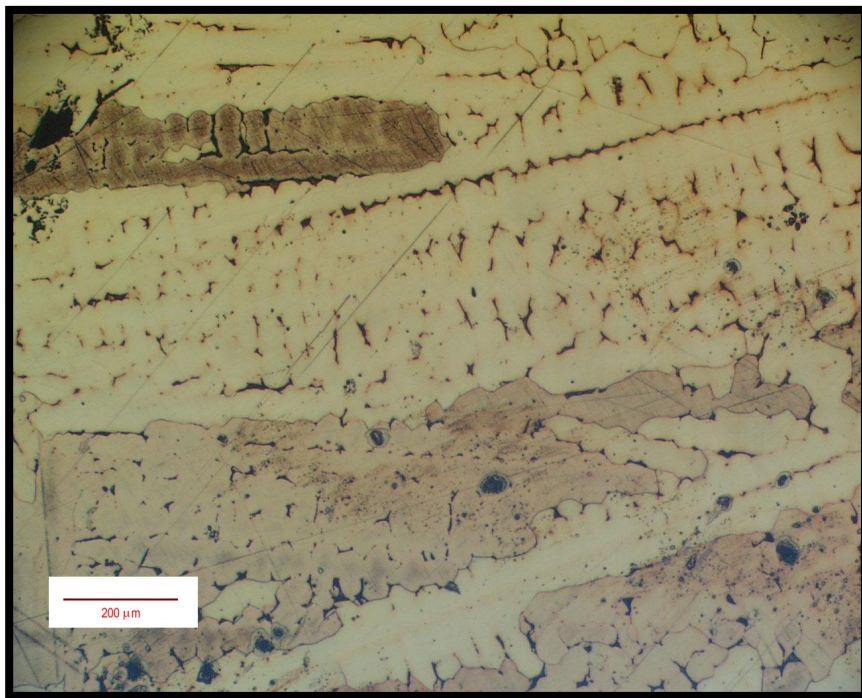


Figure 8 Etched Cu-37% Zn viewed under microscope

X10 (Cu-42% Zn, as cast):

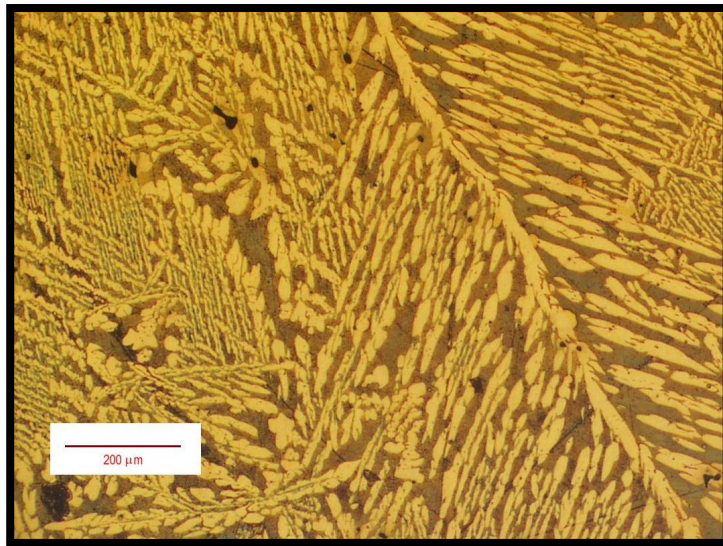


Figure 9 Etched Cu-42% Zn

X11 (Cu-42% Zn, quenched from 800°C):

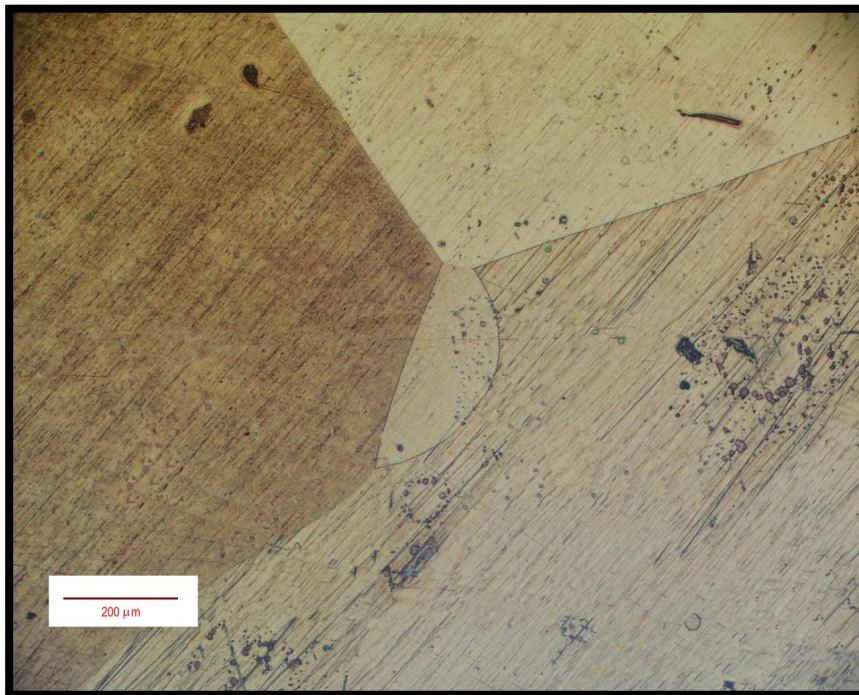


Figure 10 Etched Cu-42% Zn quenched at 800° C

Discussion

X2 (Cu/4% Sn - as cast)

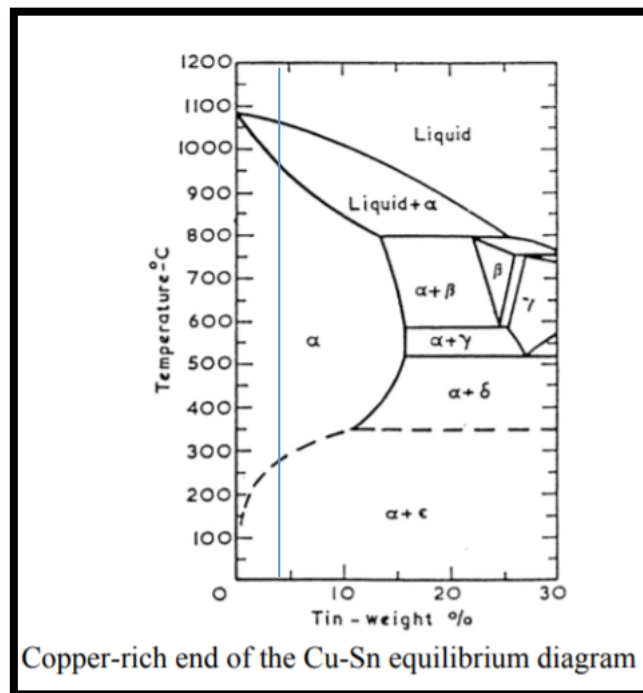


Figure 11 Copper-rich end of the Cu-Sn equilibrium diagram

At 1060° C (refer to fig.11), the alloy first starts to solidify and is completely solidified at 950° C. The percentage of Sn in the first solid formed is 0.8%. As the alloy cools down, the alpha phases solidify first with low tin concentration which increases with diffusion and as temperature goes down. However, when the cooling rate is too fast for diffusion to occur quickly there is a concentration gradient of the constituents within islands which are referred to as coring. Whilst cooling down, the dissolved gases from the environment bubble out to form porosities and thus weakens the structure.

X3 (Cu/4% Sn - homogenised)

Heating the alloy to a temperature below the melting point increases the kinetic energy of the particles within the alloy and thus facilitate the diffusion of the constituents down the concentration gradient removes the coring. There is no change in porosity because this is not removed by homogenization. There is a lack of contrast is due to the lack of coring. The dendritic shrinkage cavities are due to an increased stress field. The homogeneity increases the strength of the material compared to X2.

X5 (Cu-8.4% P, eutectic composition)

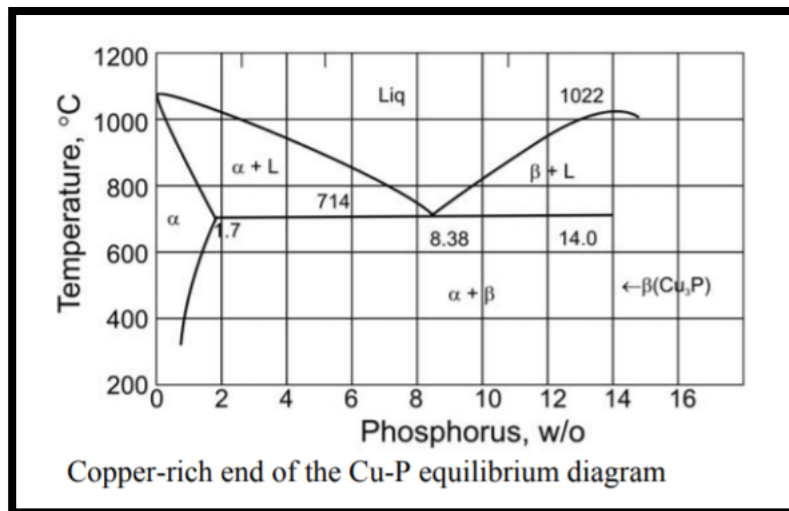


Figure 12 Copper rich end of the Cu-P equilibrium diagram

The liquid cools down until it reaches the eutectic temperature where it solidifies immediately. It will not have a pasty appearance because there is no mixture of solid and liquid phases. Since this happens very quickly, the alloy assumes a lamellar microstructure which facilitates the most diffusion due to having shortest diffusion distances. There are cracks in the etched surface which is due to the rapid freezing. Using the phase rule in figure 12, it was determined that there was 42.6% and 57.4% of α and β phases respectively at 600 °C. Using the same technique, the composition of the alloy was found to be 57.5% and 42.5% of α and β phases respectively at 400° C.

X6 (Cu-4.5% P, hypoeutectic):

As the temperature cools down, the α -phase solidifies first 920° C. This causes islands of pro-eutectic α phases and as the temperature reaches the solidus line, the rest of the liquid assumes the eutectic composition and solidifies in a similar fashion to X5. This can be seen in figure 6 where the area surrounding the island have a lamellar structure. The percentage composition of the solid and liquid phases was found to be 42% and 58% respectively at the eutectic temperature. Immediately after solidification, the percentage composition of α and β phases are 58.1% and 41.9% respectively.

X7 (Cu-10.5% P, hypereutectic):

As the temperature cools down, the α -phase solidifies first 820° C. This causes islands of pro-eutectic β phases and as the temperature reaches the solidus line, the rest of the liquid assumes the eutectic composition and solidifies in a similar fashion to X5. The

X8 (Cu-37% Zn, as cast):

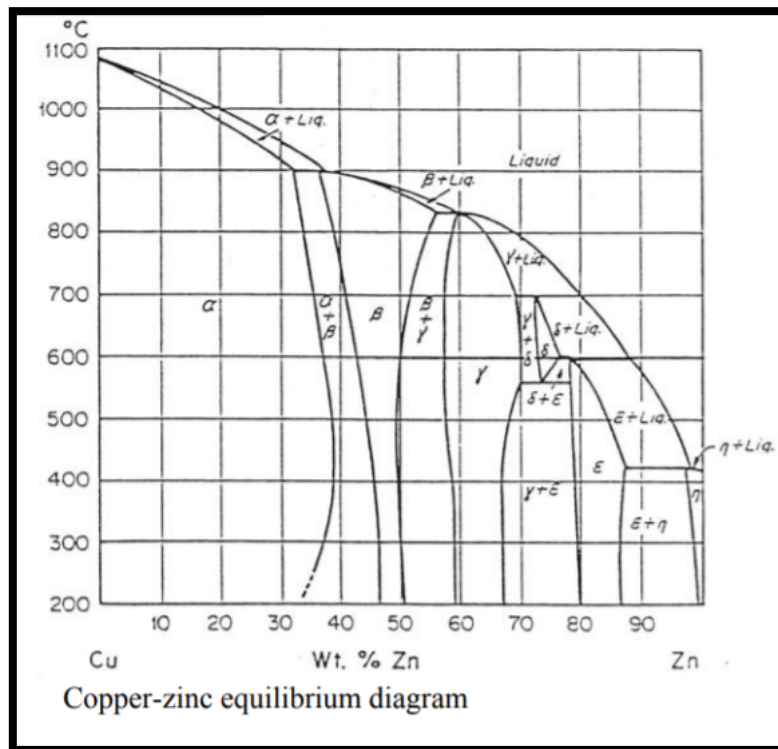


Figure 13 Copper Zinc equilibrium diagram

The liquid alloy cools down and the α phase first solidifies followed by the β phase. There is a diffusion of constituents between the α and β phase where there is a transition to a β phase only alloy. The white, brown and black parts in figure 7 are matrix, the α phase and the β phase. This is representative of the minimal β phase. The diffusion of the constituents causes the β phase to surround the α phase. The matrix cannot be determined as α and β phase because of the orientation at which it is cut.

X10 (Cu-42% Zn, as cast):

The liquid cools down and the alloy solidifies to have a single β phase. As the temperature goes down, there is diffusion of the constituents to cause the formation of the α phase at the grain boundaries. This causes the microstructure to look lamellar, however it is classified as widmanstatten pattern. Since the diffusion is slowed down as the temperature falls, there is a smaller weight fraction of α compared to β phase. The α phase can be approximated to 20% of the microstructure and the remaining of the microstructure is β phase. This is similar to the volume fraction, if the density of the α and β phases is assumed to be the same.

X11 (Cu-42% Zn, quenched from 800°C):

This alloy is quenched at 800° C and the rapid rate of cooling causes minimal diffusion and thus minimal transformation of the β phase to α and β phase. This results in a very fine widmanstatten fingers.

Conclusion

The use of the same compositional alloys but different heat treatments yielded in different microstructures. This means that the phase diagram can be used to determine the phase of the diagrams in equilibrium state and you cannot see the transition of phases during the non-equilibrium conditions.