Mechanical Properties Of Isomorphous Alloys

We shall now briefly explore how the mechanical properties of solid isomorphous alloys are affected by composition as other structural variables (e.g., grain size) are held constant. For all temperatures and compositions below the melting temperature of the lowest-melting component, only a single solid phase will exist. Therefore, each component will experience solid-solution strengthening or an increase in strength and hardness by additions of the other component. This effect is demonstrated in Figure 7*a* as tensile strength versus composition for the copper–nickel system at room temperature; at some intermediate composition, the curve necessarily passes through a maximum. Plotted in Figure 7*b* is the ductility (%EL)–composition behavior, which is just the opposite of tensile strength; that is, ductility decreases with additions of the second component, and the curve exhibits a minimum.

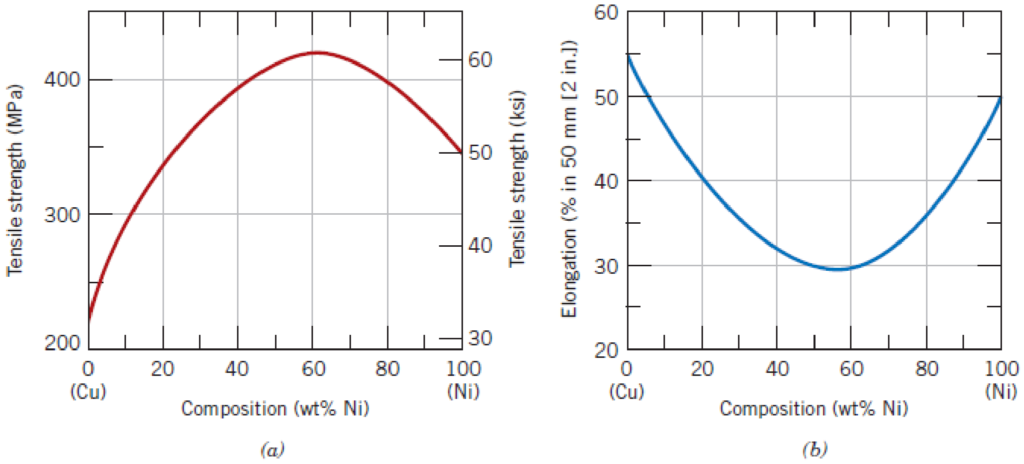

Figure 7: For the copper–nickel system, (*a*) tensile strength versus composition, and (*b*) ductility (%EL) versus composition at room temperature. A solid solution exists over all compositions for this system.

1. Binary Eutectic Systems

Another type of common and relatively simple phase diagram found for binary alloys is shown in Figure 8 for the copper–silver system; this is known as a binary eutectic phase diagram. A number of features of this phase diagram are important and worth noting. First, three single-phase regions are found on the diagram: α, β, and liquid. The α phase is a solid solution rich in copper; it has silver as the solute component and an FCC crystal structure.

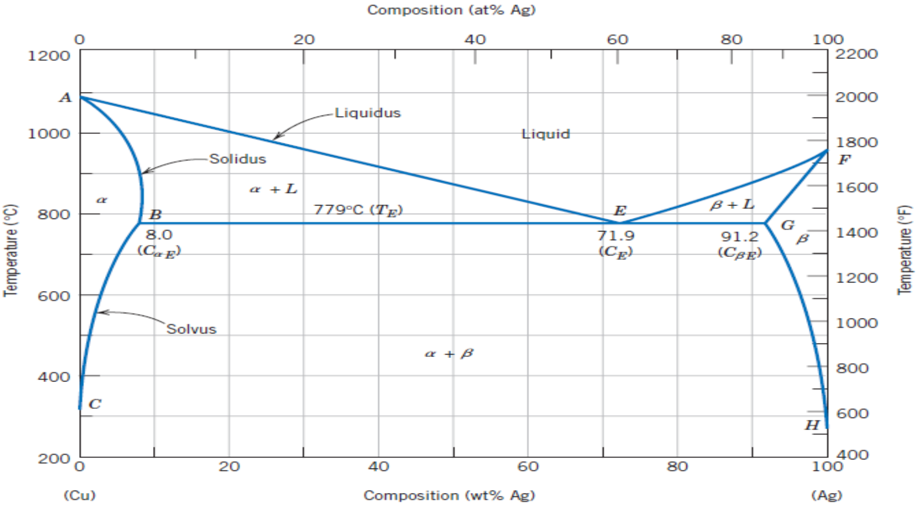

Figure 8: The copper- silver phase diagram

The β -phase solid solution also has an FCC structure, but copper is the solute. Pure copper and pure silver are also considered to be α and β phases, respectively.

Thus, the solubility in each of these solid phases is limited, in that at any temperature below line *BEG* only a limited concentration of silver will dissolve in copper (for the α phase), and similarly for copper in silver (for the β phase). The solubility limit for the α phase corresponds to the boundary line, labeled *CBA*, between the $\alpha/(\alpha+\beta)$ and $\alpha/(\alpha+L)$ phase regions; it increases with temperature to a maximum [8.0 wt% Ag at 779ºC (1434ºF)] at point *B*, and decreases back to zero at the melting temperature of pure copper, point *A* [1085ºC (1985ºF)]. At temperatures below 779ºC (1434ºF), the solid solubility limit line separating the α and $\alpha+\beta$ phase regions is termed a ***solvus line;*** the boundary *AB* between the α and $\alpha+L$ fields is the ***solidus line***, as indicated in Figure 8. For the β phase, both solvus and solidus lines also exist, *HG* and *GF*, respectively, as shown. The maximum solubility of copper in the β phase, point *G* (8.8 wt% Cu), also occurs at 779ºC (1434ºF).

This horizontal line *BEG*, which is parallel to the composition axis and extends between these maximum solubility positions, may also be considered a solidus line; it represents the lowest temperature at which a liquid phase may exist for any copper– silver alloy that is at equilibrium.

There are also three two-phase regions found for the copper–silver system (Figure 8): $\alpha+L$, $\beta+L$, and $\alpha+\beta$. The α- and β-phase solid solutions coexist for all compositions and temperatures within the $\alpha+\beta$ phase field; the α +liquid and β + liquid phases also coexist in their respective phase regions. Furthermore, compositions and relative amounts for the phases may be determined using tie lines and the lever rule as outlined previously.

As silver is added to copper, the temperature at which the alloys become totally liquid decreases along the ***liquidus line,*** line *AE*; thus, the melting temperature of copper is lowered by silver additions. The same may be said for silver: the introduction of copper reduces the temperature of complete melting along the other liquidus line, *FE*.

These liquidus lines meet at the point E on the phase diagram, through which also passes the horizontal isotherm line BEG. Point E is called an ***invariant point,*** which is designated by the composition C_E and temperature T_E; for the copper–silver system, the values of CE and TE are 71.9 wt% Ag and 779ºC (1434ºF), respectively.

An important reaction occurs for an alloy of composition C_E as it changes temperature in passing through T_E; this reaction may be written as follows:

$$L(C_E) \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha(C_{\alpha E}) + \beta(C_{\beta E})$$

Or, upon cooling, a liquid phase is transformed into the two solid α and β phases at the temperature TE; the opposite reaction occurs upon heating. This is called a ***eutectic reaction*** (*eutectic* means "easily melted"), and C_E and T_E represent the eutectic composition and temperature, respectively; $C_{\alpha E}$ and $C_{\beta E}$ are the respective compositions of the α and β phases at T_E. Thus, for the copper–silver system, the eutectic reaction, Equation above, may be written as follows:

$$L(71.9\ \text{wt\%}\ \text{Ag}) \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha(8.0\ \text{wt\%}\ \text{Ag}) + \beta(91.2\ \text{wt\%}\ \text{Ag})$$

Often, the horizontal solidus line at T_E is called the *eutectic isotherm*.

The eutectic reaction, upon cooling, is similar to solidification for pure components in that the reaction proceeds to completion at a constant temperature, or isothermally, at T_E. However, the solid product of eutectic solidification is always two solid phases, whereas for a pure component only a single phase forms. Because of this eutectic reaction, phase diagrams similar to that in Figure 8 are termed ***eutectic phase diagrams***; components exhibiting this behavior comprise a *eutectic system*.

In the construction of binary phase diagrams, it is important to understand that one or at most two phases may be in equilibrium within a phase field. This holds true for the phase diagrams in Figures 4*a* and 8. For a eutectic system, three phases (α ,β , and *L*) may be in equilibrium, but only at points along the eutectic isotherm. Another general rule is that single-phase regions are always separated from each other by a two-phase region that consists of the two single phases that it separates. For example, the α + β field is situated between the α and β single-phase regions in Figure 8.