Utilization of Phase Diagrams

Phase diagrams are justifiably regarded as an important component of our technological society; the *Bulletin* will publish examples that illustrate their value in the development of new science and trouble shooting and, in this issue, manufacturing control and the development of new materials. Readers are invited to share their experiences by submitting items to the Editor, in any area of application.

Fe-Cr-Co Permanent Magnet Alloys

Permanent magnet alloys made from iron, chromium, and cobalt have aroused much interest, because of their good ductility and excellent magnetic properties, in replacing available ductile magnets and some of the Alnico alloys in the present permanent magnet market. The magnetic hardening of the Fe-Cr-Co alloys is associated with their fine two-phase microstructures. The fine microstructures can be achieved by aging within the miscibility gap of the system. Thus, in order to control the magnetic properties of the alloys, it is important to know the shape of the miscibility gap of the system. Thermodynamic computations of the miscibility gap of an Fe-Cr-Co system by Nishizawa *et al.* predicted that the miscibility gap of the system has a peculiar "ridge" protruding out along the Curie temperature. The characteristics of the ridge shape are speculated to be desirable for the effective magnetic aging and the achievement of high volume fraction of the ferromagnetic phase in Fe-Cr-Co hard magnetic alloys. Homma *et al.* experimentally confirmed the existence of

ridge region of the miscibility gap in the system and found that the thermomagnetic treatment in the ridge region is effective in aligning and elongating the ferromagnetic particles parallel to the applied magnetic field direction, resulting in a remarkable improvement of the magnetic properties of the alloys. This is a good example that thermodynamic computations of the phase diagram give useful and important information in designing good permanent magnet alloys.

References

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Application of Phase Diagrams in Solidification and Casting Problems

The analysis of problems involving the casting of alloys requires a complex blend of fluid mechanics, heat flow, chemical diffusion and solid mechanics. However, the phase diagram, especially when applied to the character of a material at a given position and time (local equilibrium), provides the basic constitutive relation regarding the physical state of the alloy. To say that a phase diagram can alone describe all of the details of cast structure is as absurd as stating that Hooke's law can describe all problems in linear elasticity. The information of a phase diagram must be placed upon a framework of balanced equations that describe the kinetics of a given situation. Since 1950, great progress has been made in the analysis of solidification problems using this concept of local equilibrium.

A major use of phase diagrams comes about in the prediction of the degree of microsegregation and inclusion (or second-phase) formation. Modern approaches to the microsegregation problem accept the inevitable difficulty of solid state chemical diffusion compared to the liquid state and replace mass balance accompanied by complete diffusion, i.e., the "lever rule" with mass balance accompanied by incomplete diffusion (the Scheil equation). This equation when coupled with the partition coefficients of the various solutes can be used to estimate the liquid composition (and solid composition) as a function of fraction solid or, equivalently, the fraction solid as a function of temperature. Partition coefficients can be read directly from the phase diagram. Additionally, the solidification path can be calculated and the prediction made of the

fraction solid when the liquid can begin formation of second-phase particles, inclusions or eutectics. Such liquid compositions are directly read from phase diagrams. This analysis yields an estimate for the volume fraction of all the phases that will occur in the cast structure, as well as the magnitude of concentration gradients which will exist in the cast solid. In the prediction of macrosegregation, the mass balance is augmented by fluid flow terms to predict local increases or decreases in the fraction of second-phase particles and concomitant shifts in the average composition in that location. Such analysis has been successfully applied to describe chill zone, centerline, cross section change and "V" segregation. Data for this require parameters read directly from phase diagrams.

The prediction of fraction solid as a function of temperature described above, when coupled with a thermal analysis of castings, yields the thickness of the mushy zone or liquid-solid region in castings. The thickness of the mushy zone is very important for the prediction and control of microporosity and gas porosity, as well as hot tearing characteristics of castings. The former are generally caused by the difficulty of fluid flow through the mushy zone to feed solidification shrinkage, whereas the latter is caused by the formation of large thermal contraction stresses acting on an insufficiently strong solid in a mushy zone. Gas porosity analysis also requires data regarding the solubility of gases in metals. Mushy-zone thickness has also been associated with grain multiplication and the formation of equiaxed grain zone of ingot castings.

Theories of dendrite coarsening, which lead to predictions of dendrite arm spacings in castings as a function of local solidification time, rely on the partition coefficient and liquidus slope from the phase diagram as parameters.