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Al-Mn-Ni (Aluminum-Manganese-Nickel)

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The previous review/compilation of the data on this ternary system by [1993Suz] and [1995Vil] presented a liquidus projection, partial isothermal sections, and vertical sections from the work of [1938Kos] and [1944Ray]. Among the more recent work included in the above are an isothermal section at 1000 °C from [1977Cha] and a vertical section along the Ni_3Al-Ni_3Mn join from [1988Wac]. Recently, [1993Pov] found an Al-rich ternary phase at the composition Mn_3NiAl_{10} and [1998Kai] determined three isothermal sections at 1100, 1000, and 850 °C.

Binary Systems

The Al-Mn phase diagram [1996Liu, 1996Mul] depicts a number of complex intermediate phases in the Al-rich region, see [Massalski2] for a list. In the midatomic region, two intermediate phases with simple structures are present: the body-centered-cubic (bcc) phase (called γ) and the close-packed-hexagonal (cph) phase (ε). The homogeneity ranges of these phases determined by [1996Liu] and [1996Mul] are significantly different from each other. The phase boundaries of [1996Liu] are used tentatively in this review. The Al-Ni phase diagram [1993Oka] shows five intermediate phases: $NiAl_3$ ($D0_{11}$, Fe_3C-type orthorhombic), Ni_2Al_3 ($D5_{13}$-type hexagonal), NiAl (*B*2, CsCl-type cubic, also denoted β), Ni_5Al_3 (Ga_3Pt_5-type orthorhombic), and Ni_3Al ($L1_2$, $AuCu_3$-type cubic; also denoted γ′). The Mn-Ni phase diagram given in [Massalski2] appears to be obsolete. Figure 1 shows the Mn-Ni diagram computed by [2005Guo], incorporating the recent experimental results of [2002Din]. [2002Din] investigated 47 binary alloys in the composition range of 25 to 70 at.% Ni, using annealing times of 3 to 7 months between 850 and 500 °C. They found only the *B*2 and $L1_0$ structures around the midcomposition. Likewise, [1995Col] found only the $L1_0$ structure between 565 and 500 °C. In Fig. 1, MnNi (HT) (HT stands for high-temperature form; denoted αMnNi by [2005Guo]) has the *B*2, CsCl-type cubic structure. MnNi (LT) (denoted βMnNi by [2005Guo]) has the $L1_0$, AuCu-type tetragonal structure. Two other Mn-rich compounds are known: $MnNi_2$ and $MnNi_3$ ($L1_2$, $AuCu_3$-type cubic).

Ternary Phases

[1995Vil] listed six ternary phases. Two of these are based on the binary *B*2 phase and two others are based on the binary $L1_2$ phase. $AlMnNi_2$ is a Heusler-type phase that forms through a second-order transition from *B*2 below 500 °C [1998Sut]. $Mn_6Ni_2Al_{31}$ is orthorhombic, space group *Cmcm* [Pearson3]. The structure of Mn_3NiAl_{10} found by [1993Pov] is not known. It appears to be related to Fe_3NiAl_{10} and could be a quasi-crystalline phase, see [2005Rag] for a brief discussion. It crystallizes at 980 °C and forms tie-lines at 900 °C with *B*2 and Mn_2Al_3 phases [1993Pov].

Isothermal Sections

With starting metals of Al (99.7 wt.%), Mn (99.9 wt.%), and Ni (99.9 wt.%), [1998Kai] induction melted alloys under Ar atm. Diffusion couples were annealed at 1100 to 850 °C for 2 to 336 h. The microstructures were examined by optical microscopy. The compositions of coexisting phases after the diffusion anneal were measured by the energy dispersive x-ray spectroscopy. Combining their experimental results with those of [1994Jia], [1998Kai] constructed three isothermal sections at 1100, 1000, and 850 °C, which are redrawn in Fig. 2 to 4 to agree with the accepted binary data.

At 1100 °C (Fig. 2), (Ni), liquid and (γMn) are present along the Mn-Ni axis. The *B*2 phase exists over a large composition range. A two-phase equilibrium exists between *B*2 and the disordered bcc phase based on δMn. With increasing Al, the two-phase region disappears and the *B*2-*A*2 boundary becomes second order. At higher Al contents, the cph ε phase of the Al-Mn system becomes stable and forms tie-lines with *B*2. At still higher Al concentration, the intermediate phase γ (bcc) of the Al-Mn system is stable. Its relation to the *B*2 phase was not clarified by [1998Kai]. At

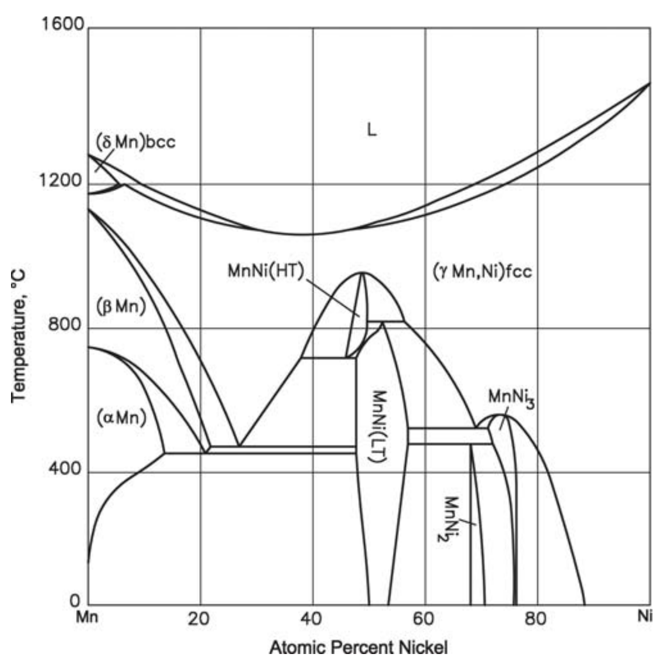

Fig. 1 Mn-Ni computed phase diagram [2005Guo]

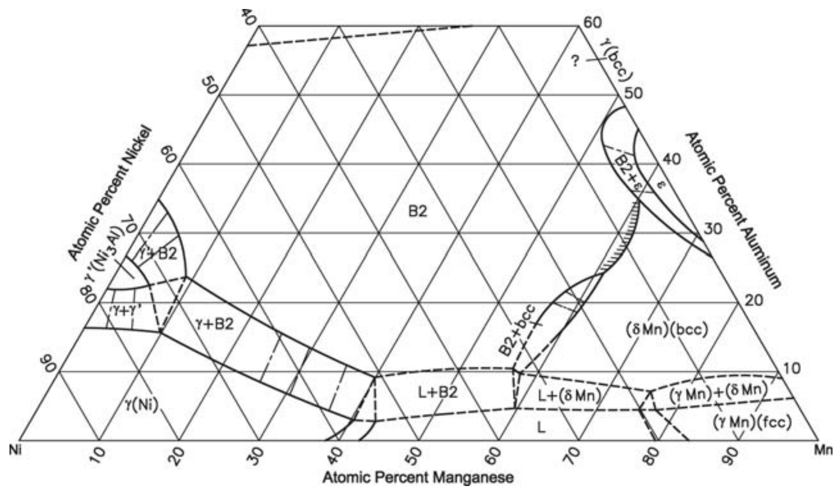

Fig. 2 Al-Mn-Ni isothermal section at 1100 °C [1998Kai]

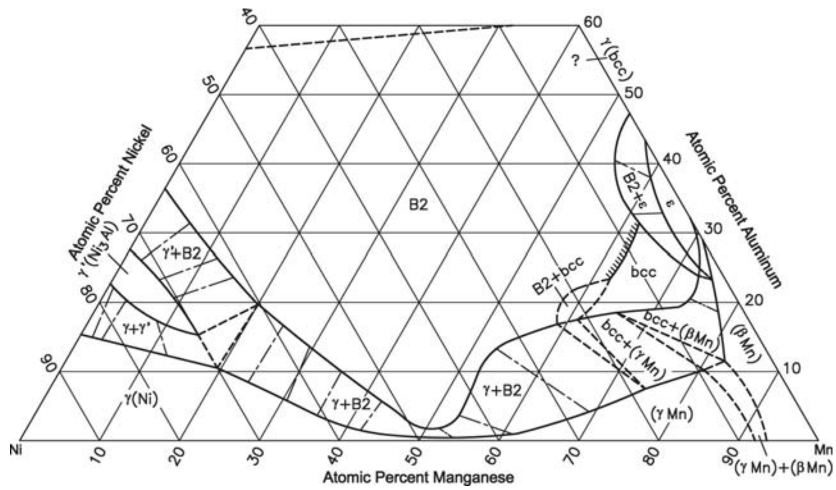

Fig. 3 Al-Mn-Ni isothermal section at 1000 °C [1998Kai]

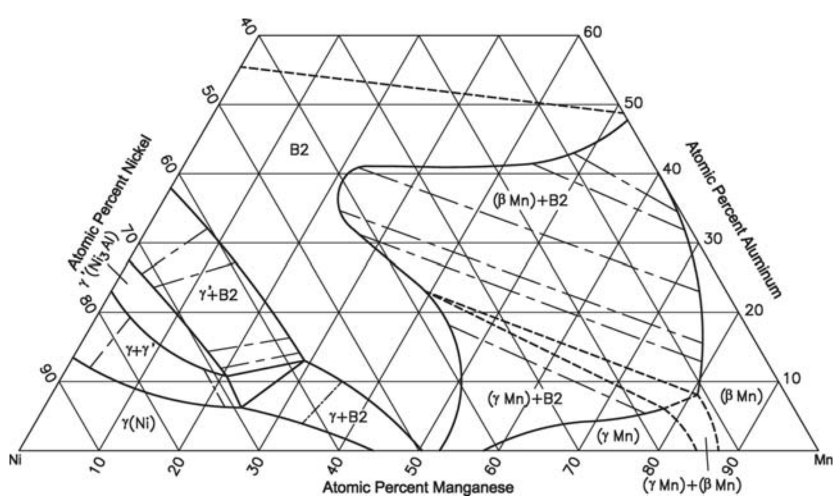

Fig. 4 Al-Mn-Ni isothermal section at 850 °C [1998Kai]

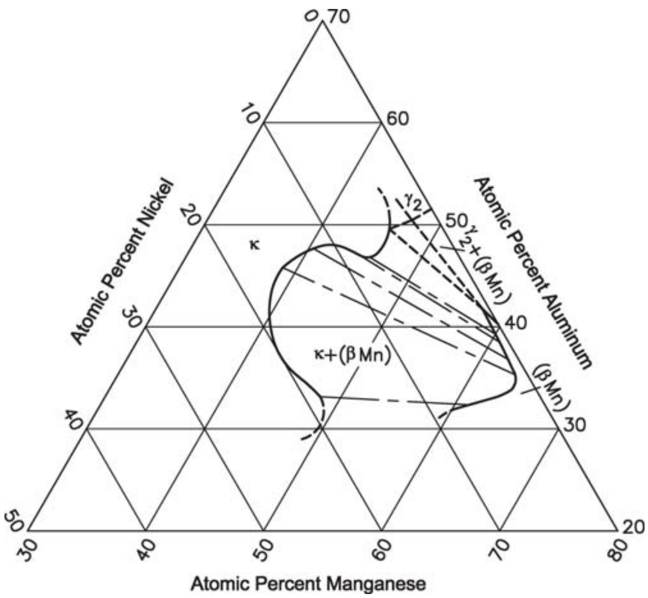

Fig. 5 Al-Mn-Ni partial isothermal section at 700 °C [1997Mul]

1000 °C (Fig. 3), a continuous solid solution exists between (Ni) and γMn. The δMn-based bcc phase recedes into the ternary region. It forms tie-lines with *B*2 at lower Al contents. A second-order boundary is seen at higher Al values. Comparing Fig. 3 with the isothermal section at 1000 °C determined by [1977Cha] (not shown here), it is seen that the *B*2 phase extends to much lower Al contents in Fig. 3. [1977Cha] found evidence for the disordered bcc phase near the Al-Mn γ phase and suggested a two-phase field between γ (bcc) and *B*2. At 850 °C (Fig. 4), a continuous *B*2 solid solution exists between NiAl and MnNi (HT) [2001Tan]. Both (γMn) (fcc) and (βMn) (*A*13) form tie-lines with *B*2. The homogeneity region of *B*2 has shrunk at 850 °C, especially along the line joining the Mn corner to NiAl. In Fig. 2 to 4, the (Ni)-Ni_3Al (γ′) and γ′-*B*2 tie-lines are from [1994Jia].

[1997Mul] found that the addition of Ni to near-equiatomic Al-Mn alloys does not result in the stabilization of the metastable τ (AuCu-type tetragonal) phase found in the Al-Mn binary system. A partial isothermal section determined by [1997Mul] at 700 °C (Fig. 5) depicts tie-lines between (βMn) and a magnetic phase κ (in the absence of τ). The κ phase, so called by [1961Tsu], has the *B*2 structure with a = 0.2970 to 0.2920 nm [1961Tsu]. Its relation to NiAl (*B*2) (or to the martensitic tetragonal form of NiAl) is not known.

The Ni_3Al-Ni_3Mn Vertical Section

Using starting metals of Al (99.99 wt.%), Mn (99.995 wt.%), and Ni (99.999 wt.%), [1988Wac] induction melted under Ar atm 15 alloys in the composition range of $Ni_{75}Mn_xAl_{25-x}$ ($0 \le x \le 25$). The phase equilibria were investigated by the magnetothermal analysis. The vertical section constructed by [1988Wac] along the Ni_3Al-Ni_3Mn join is redrawn in Fig. 6. This is in good agreement with the section determined by [1986Mas], employing metallography, x-ray diffraction, and electron probe microanalysis. However, the same section redetermined by [1998Gom] using neutron diffraction and calorimetry contradicts the above results. [1998Gom] depicted it as a pseudobinary section between two continuous solid solutions γ and γ′, ignoring the known peritectic solidification of Ni_3Al (γ′). Figure 6 includes the lattice parameter measurements of γ′ ($L1_2$) at room temperature by [1986Mas].

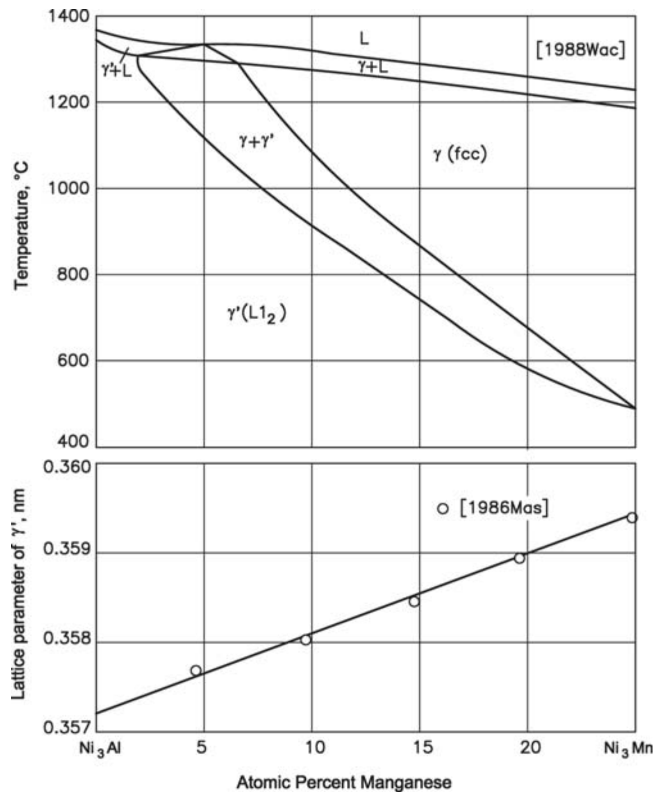

Fig. 6 Al-Mn-Ni vertical section along the Ni_3Al-Ni_3Mn join

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