Aluminium – Cadmium – Magnesium

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Literature Data

There are many data available on the phase equilibria in the Al-Cd-Mg ternary system. The liquidus surface is reported by [1925Val, 1926Val, 1935Hau, 1937Koe, 1938Jae, 1938Rie, 1946Mik]. The isothermal sections have been reported by various groups, at 395°C by [1946Mik], 302°C by [1993Kal], 230°C by [1938Rie] and [1946Mik] reports the phase equilibria at room temperature (25°C). Several vertical sections are given by [1926Val, 1937Koe, 1946Mik].
[1925Val] and [1926Val] investigated the system by thermal analysis and studied the alloys' microstructures; which allowed them to determine the boundaries of the miscibility gap, the liquidus surfaces and phase transformations involved, across the entire composition range of the system.
The liquidus surface and the (Mg) solid solubility limits in alloys containing up to 22Al-5.2Cd (at.%) were examined by [1935Hau] using thermal analysis and metallography. The Mg corner of the Al-Cd-Mg phase diagram was investigated by [1937Koe]. There is agreement between the results of [1935Hau] and [1937Koe]. [1938Rie] investigated numerous alloys by X-ray diffraction and metallography, constructed a projection of the liquidus surface, an isothermal section at 230°C and re-determined the boundaries of the miscibility gap. The liquidus and solidus surfaces proposed by [1938Jae] show invariant reactions and strongly contradict both, the result [1938Rie] and the accepted Al-Cd binary system.
[1946Mik] also investigated many alloys by thermal analysis and metallography. From this work results a description of the liquidus surface, 13 isopleths and isothermal sections at 25 and 395°C. Solid phase interactions in the system at 302°C have been examined by [1993Kal] by means of superposition of diffusion zones and the isothermal section at this temperature was constructed. The purity of the starting materials was better than 99.99% for Al and Cd and 99.95% for Mg.
The present evaluation was published in the MSIT Evaluation Program earlier and reflects today's state of knowledge.

Binary Systems

The binary phase relations for the systems Al-Cd and Cd-Mg are accepted as described by [Mas2]. For the Al-Mg phase diagram several different versions have been proposed over time. The most consistent description is that by [2003Luk] which is integrated into the present evaluation. It is based on experimental investigations of the Al-Mg system between 47 and 63 at.% Al, and calculated phase diagram equilibria presented by [1998Lia].

Solid Phases

No ternary compounds have been found in the Al-Cd-Mg system. The crystal structures of the binary phases are listed in Table 1. Adding Cd decreases the solubility of Al in solid (Mg) [1935Hau, 1937Koe, 1946Mik], how Cd effects the solubility of Al at different temperatures [1935Hau] is shown in Fig. 1. The results of [1935Hau] agree with those of [1937Koe] and seem to be reliable. The β phase can take up to about 1 at.% Cd at 395°C and about 0.6 at.% Cd at 20°C [1946Mik]. The γ phase contains at these temperatures more than 5 at.% Cd and 4 at.% Cd [1946Mik]. The solid solubility of Al in (Mg,Cd) at room temperature seems to be negligible [1946Mik]. The solubility of Cd at 302°C in the Al-Mg phases β, γ, and ε as found by [1993Kal] are listed in Table 2. The ordered phases of the Cd-Mg system have the following concentration limits: α′ ($MgCd_3$) - from 25 to 32 at.% Mg, α′′ (MgCd) - from 38 to 60 at.% Mg, α′′′ (Mg_3Cd) - from 65 to 82 at.% Mg.

Invariant Equilibria

The invariant equilibria have not been determined reliably yet in spite of the many investigations. [1925Val] and [1926Val] reported a eutectic reaction at 395°C with the eutectic point at about 45Mg-37.5Cd-17.5Al (at.%). This result is close to that of [1946Mik] who reported a ternary eutectic equilibrium point at 54Mg-32Cd-14Al (at.%) and 396 ± 0.5°C. However, in the diagram presented the ternary eutectic point is approached by only two monovariant eutectic reactions: L⇌(Al)+β and L⇌γ+(Mg,Cd). This is incorrect because it indicates an equilibrium of five phases at the eutectic point. Thus, it is not clear which solid phases are formed during the ternary eutectic reaction [1925Val, 1926Val]. The data of [1926Val] suggests the occurrence of a reaction $L_1 \rightleftharpoons L_2$+(Al)+X where X is most likely the β phase, but there is no proof of this in the literature. [1976Mon] proposed a similar reaction, with the X phase being unknown. [1938Rie] informs about two invariant equilibria in this system, but the nature and temperatures of the invariant equilibria are not clear.
The invariant equilibria proposed by all these works can not be accepted because they are contradictory and adopted on incorrect Cd-Mg phase diagram.

Liquidus Surface

Figure 2 shows a tentative liquidus surface. The region of immiscibility after [1946Mik] extends up to 53Mg-15Al (at.%) and is appreciably larger than determined by [1926Val, 1938Jae, 1938Rie]. The isotherms of the liquidus surface are taken from [1946Mik] with minor corrections according to the accepted binary diagrams.

Isothermal Sections

Isothermal sections of the Al-Cd-Mg phase diagram are reported by [1938Rie, 1938Jae, 1946Mik, 1993Kal]. They contain a number of incorrect features originating from erroneous edge binary Cd-Mg and Al-Mg systems and have been amended accordingly. The isothermal sections of Figs. 3 and 4 are based on [1938Rie, 1946Mik, 1993Kal] with modification being applied to match with the accepted edge binary systems.
The compositions of coexisting phases in the three-phase equilibria at 302°C were determined by [1993Kal] by microprobe analyses (see Table 2). These data have been used in this evaluation to construct the isothermal section at 302°C (Fig. 3).
Although [1993Kal] (Table 2) postulates a homogeneity range of about 1 at.% Mg for the ε phase, it is treated here as a line compound (Fig. 3) to be consistent with the well established Al-Mg binary diagram.
The isothermal section at 230°C after [1938Rie] was adopted to the accepted binary systems (Fig. 4). The isothermal sections constructed by [1946Mik] for temperatures of 25 and 395°C are incompatible with both, the accepted binary phase diagrams and the isothermal sections after [1938Rie] and [1993Kal] at 302°C and at 230°C. Therefore these data are not presented here.

References

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Table 1: Crystallographic Data of Solid Phases

Phase / Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(Al) < 660	*cF*4 $Fm\bar{3}m$ Cu	*a* = 404.96	pure Al at 25°C [Mas2]
δ(Mg,Cd) < 650	*hP*2 $P6_3/mmc$ Mg	*a* = 297.88 *c* = 561.67 *a* = 320.94 *c* = 521.05	pure Cd at 21°C [Mas2] pure Mg at 25°C [Mas2]
β, Mg_2Al_3 < 452	*cF*1168 $Fd\bar{3}m$ Mg_2Al_3	*a* = 2823.9	1168 atoms on 1704 sites per unit cell [2003Luk] 60-62 at.% Al [1997Su]
ε, $Mg_{23}Al_{30}$ 410-250	*hR*159 $R\bar{3}$ $Mg_{23}Al_{30}$	*a* = 1282.54 *c* = 2174.78	[V-C, 1981Sch, 1968Sam] 159 atoms refer to hexagonal unit cell [2003Luk]
γ, $Mg_{17}Al_{12}$ < 458	*cI*58 $I\bar{4}3m$ αMn	*a* = 1048.11 *a* = 1053.05 *a* = 1056 *a* = 1057.91	52.58 at.% Mg [L-B] 56.55 at.% Mg [L-B] 58.62 at.% Mg ($Mg_{17}Al_{12}$) [P] 60.49 at.% Mg [L-B]

Phase / Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
α′, $MgCd_3$ < 125	*hP*8 *P6₃/mmc* Ni_3Sn	*a* = 623.35 *c* = 504.50	at 24.8 at.% Mg and 25°C [Mas2, V-C2]
α′′, MgCd < 253	*oP*4 *Pmma* AuCd	*a* = 500.51 *b* = 322.17 *c* = 527.00	at 49.7 at.% Mg and 18°C [Mas2, V-C2]
α′′′, Mg_3Cd < 186	*hP*8 *P6₃/mmc* Ni_3Sn	*a* = 631.3 *c* = 507.4	at 75.0 at.% Mg and 25°C [Mas2, V-C2]

Table 2: Solid Phases Compositions in the Three-Phase Fields of the Al-Cd-Mg System at 302°C [1993Kal]

Three-Phase Field	Phase	Composition (at.%)		
		Al	Cd	Mg
δ + β + (Al)	δ	0.9	42.1	57.0
	β	61.3	0.5	38.2
	(Al)	95.6	0.3	4.1
δ + β + ε	δ	2.1	36.9	61.0
	β	60.5	0.4	39.1
	ε	54.2	3.1	42.7
δ + ε + γ	δ	2.9	34.9	62.2
	ε	53.1	3.0	43.9
	γ	42.7	7.0	50.3

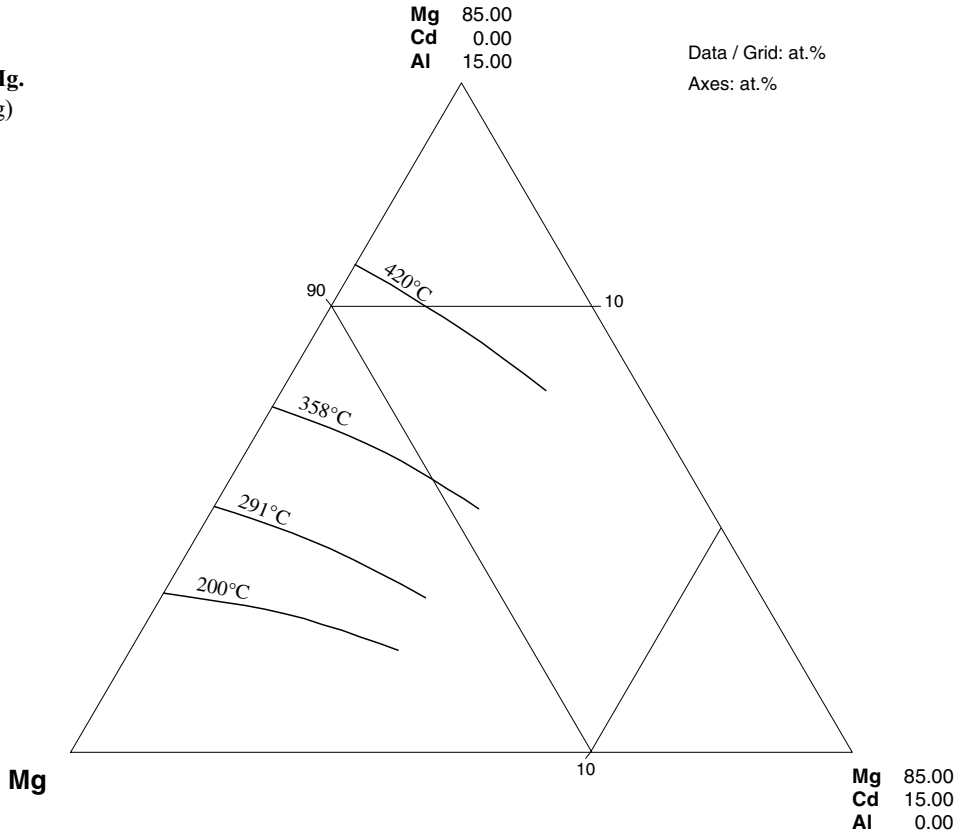

Fig. 1: Al-Cd-Mg. Boundaries of (Mg) solid solution at different temperatures

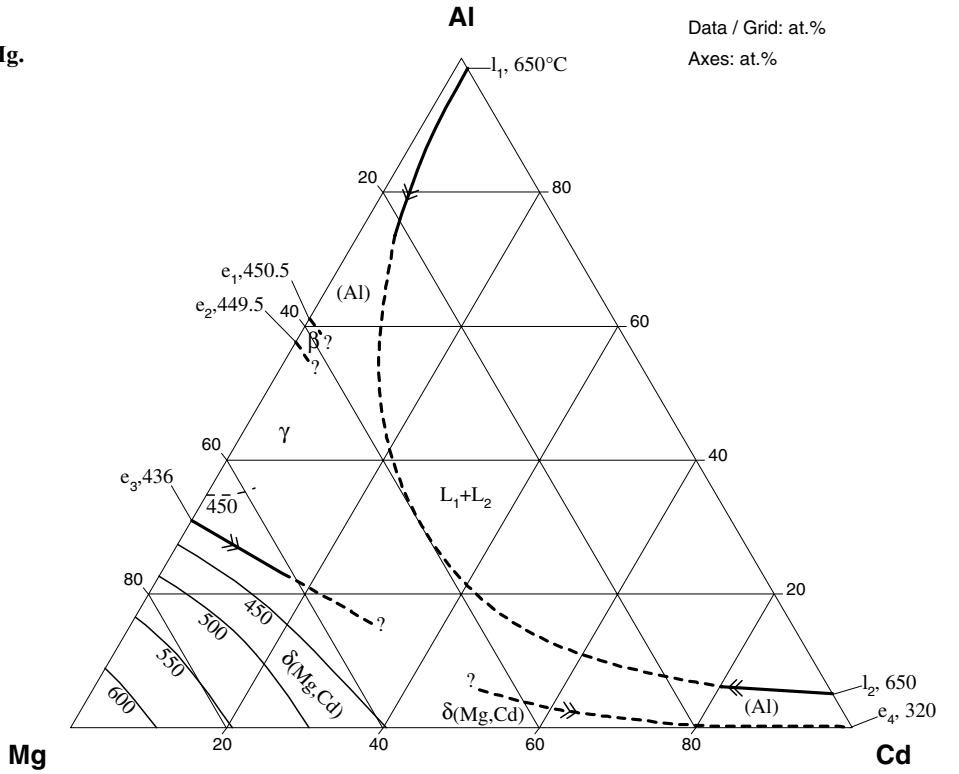

Fig. 2: Al-Cd-Mg. Tentative liquidus surface

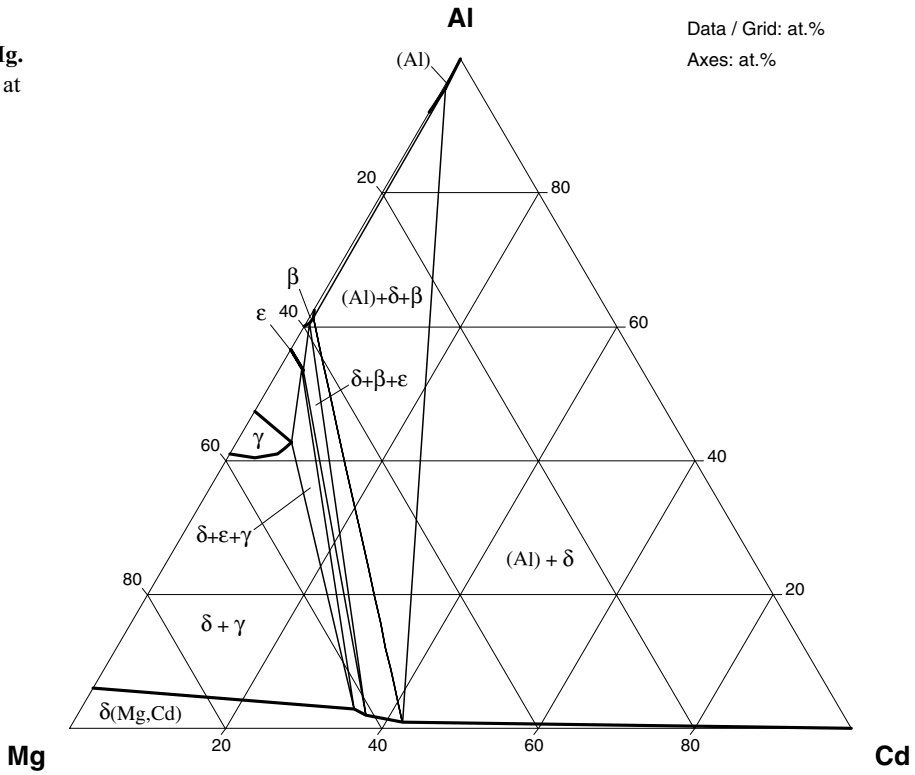

Fig. 3: Al-Cd-Mg. Isothermal section at 302°C

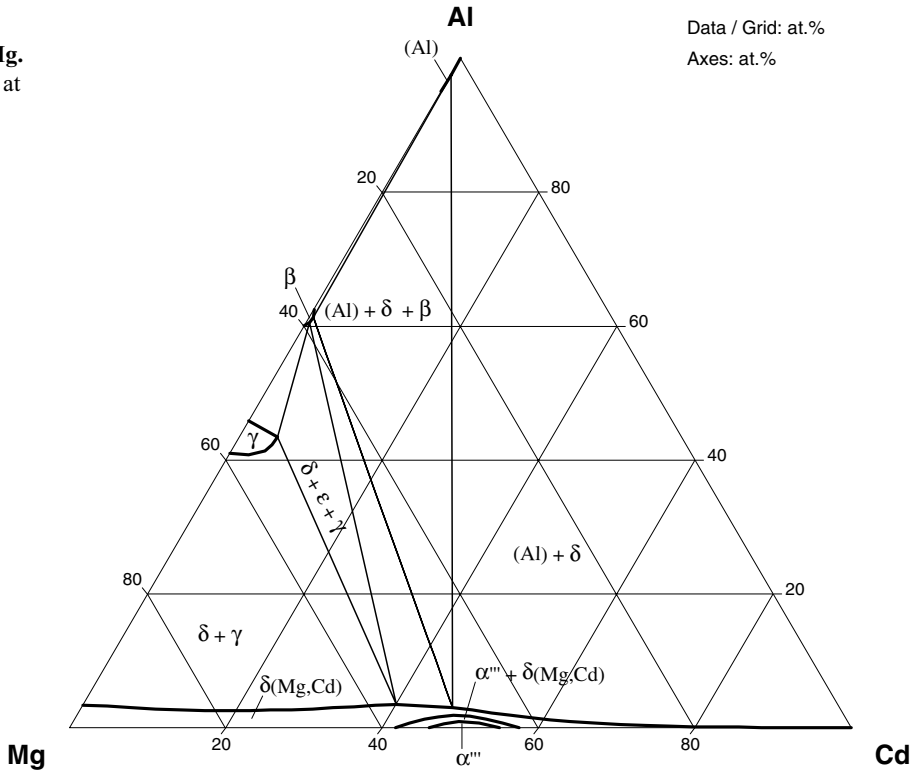

Fig. 4: Al-Cd-Mg. Isothermal section at 230°C