Gd – Mn (Gadolinium – Manganese)

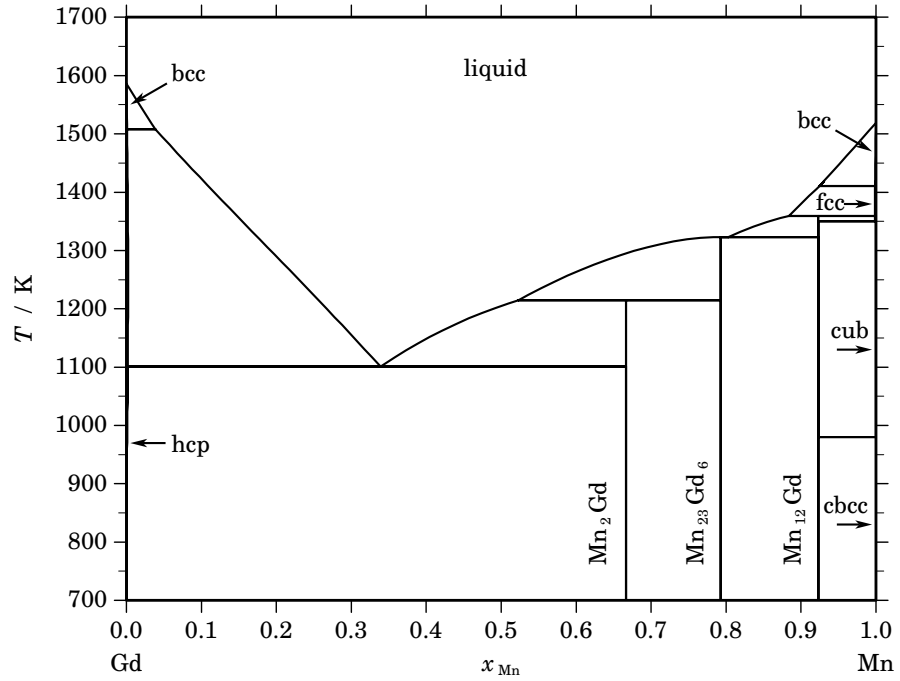

Fig. 1. Calculated phase diagram for the system Gd-Mn.

Manganese and rare earth metals are added to magnesium alloys in order to improve their creep resistance and strength. A review and a thermodynamic optimisation of the Gd-Mn system has been prepared by [2001Grö]. The phase diagram of the system Gd-Mn has been determined by Kirchmayr and Lugscheider [1967Kir]. The partial enthalpies of the components in molten Gd-Mn alloys have been measured calorimetrically by Nikolaenko and Nosova [1989Nik]. However, their data have a large range of scatter and they are not used in the optimisation [2001Grö]. Enthalpies of formation of the intermetallic compounds have been estimated from the corresponding values of the Mn-Y system which been assessed in the same publication [2001Grö].

Table I. Phases, structures and models.

Phase	Struktur-bericht	Prototype	Pearson symbol	Space group	SGTE name	Model
liquid					LIQUID	$(Gd,Mn)_1$
bcc	$A2$	W	$cI2$	$Im\overline{3}m$	BCC_A2	$(Gd,Mn)_1$
hcp	$A3$	Mg	$hP2$	$P6_3/mmc$	HCP_A3	$(Gd,Mn)_1$
Mn_2Gd	$C15$	Cu_2Mg	$cF24$	$Fd\overline{3}m$	M2R	Mn_2Gd_1
$Mn_{23}Gd_6$	$D8_a$	$Mn_{23}Th_6$	$cF116$	$Fm\overline{3}m$	M23R6	$Mn_{23}Gd_6$
$Mn_{12}Gd$	$D2_b$	$Mn_{12}Th$	$tI26$	$I4/mmm$	M12R	$Mn_{12}Gd_1$
fcc	$A1$	Cu	$cF4$	$Fm\overline{3}m$	FCC_A1	$(Gd,Mn)_1$
cbcc	$A12$	αMn	$cI58$	$I\overline{4}3m$	CBCC_A12	Mn_1
cub	$A13$	βMn	$cP20$	$P4_132$	CUB_A13	Mn_1

Table II. Invariant reactions.

Reaction	Type	T / K	Compositions / x_{Mn}			$\Delta_{\mathrm{r}}H$ / (J/mol)
bcc $\rightleftharpoons$ hcp + liquid	metatectic	1507.9	0.001	0.001	0.039	−3502
bcc $\rightleftharpoons$ liquid + fcc	metatectic	1410.8	0.999	0.925	0.999	−1905
liquid + fcc $\rightleftharpoons$ $Mn_{12}Gd$	peritectic	1359.4	0.884	0.998	0.923	−15890
fcc $\rightleftharpoons$ $Mn_{12}Gd$ + cub	eutectoid	1350.2	0.999	0.923	1.000	−2330
liquid $\rightleftharpoons$ $Mn_{23}Gd_6$	congruent	1323.2	0.793	0.793		−21254
liquid $\rightleftharpoons$ $Mn_{23}Gd_6$ + $Mn_{12}Gd$	eutectic	1323.0	0.803	0.793	0.923	−21198
liquid + $Mn_{23}Gd_6$ $\rightleftharpoons$ Mn_2Gd	peritectic	1214.7	0.523	0.793	0.667	−8918
liquid $\rightleftharpoons$ hcp + Mn_2Gd	eutectic	1100.8	0.339	0.002	0.667	−15053
cub $\rightleftharpoons$ $Mn_{12}Gd$ + cbcc	eutectoid	980.0	1.000	0.923	1.000	−2254

Table IIIa. Integral quantities for the liquid phase at 1600 K.

x_{Mn}	ΔG_{m} [J/mol]	ΔH_{m} [J/mol]	ΔS_{m} [J/(mol·K)]	$G_{\mathrm{m}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{m}}^{\mathrm{E}}$ [J/(mol·K)]	ΔC_P [J/(mol·K)]
0.000	0	0	0.000	0	0.000	0.000
0.100	−4044	−1159	1.803	281	−0.900	0.000
0.200	−6186	−2089	2.561	471	−1.600	0.000
0.300	−7545	−2779	2.979	581	−2.100	0.000
0.400	−8331	−3218	3.196	622	−2.400	0.000
0.500	−8617	−3396	3.263	604	−2.500	0.000
0.600	−8416	−3303	3.196	537	−2.400	0.000
0.700	−7693	−2927	2.979	433	−2.100	0.000
0.800	−6355	−2258	2.561	302	−1.600	0.000
0.900	−4171	−1286	1.803	154	−0.900	0.000
1.000	0	0	0.000	0	0.000	0.000

Reference states: Gd(liquid), Mn(liquid)

Table IIIb. Partial quantities for Gd in the liquid phase at 1600 K.

x_{Gd}	ΔG_{Gd} [J/mol]	ΔH_{Gd} [J/mol]	ΔS_{Gd} [J/(mol·K)]	$G_{\mathrm{Gd}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{Gd}}^{\mathrm{E}}$ [J/(mol·K)]	a_{Gd}	γ_{Gd}
1.000	0	0	0.000	0	0.000	1.000	1.000
0.900	−1355	−113	0.776	47	−0.100	0.903	1.004
0.800	−2794	−466	1.455	174	−0.400	0.811	1.013
0.700	−4385	−1080	2.066	360	−0.900	0.719	1.027
0.600	−6211	−1976	2.647	584	−1.600	0.627	1.045
0.500	−8397	−3176	3.263	825	−2.500	0.532	1.064
0.400	−11130	−4700	4.019	1060	−3.600	0.433	1.083
0.300	−14747	−6570	5.110	1270	−4.900	0.330	1.100
0.200	−19978	−8807	6.982	1433	−6.400	0.223	1.114
0.100	−29105	−11433	11.045	1527	−8.100	0.112	1.122
0.000	$-\infty$	−14468	∞	1532	−10.000	0.000	1.122

Reference state: Gd(liquid)

Table IIIc. Partial quantities for Mn in the liquid phase at 1600 K.

x_{Mn}	ΔG_{Mn} [J/mol]	ΔH_{Mn} [J/mol]	ΔS_{Mn} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Mn}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Mn}}$ [J/(mol·K)]	a_{Mn}	γ_{Mn}
0.000	$-\infty$	−12702	∞	3298	−10.000	0.000	1.281
0.100	−28247	−10575	11.045	2385	−8.100	0.120	1.196
0.200	−19752	−8581	6.982	1659	−6.400	0.227	1.133
0.300	−14920	−6743	5.110	1097	−4.900	0.326	1.086
0.400	−11511	−5081	4.019	679	−3.600	0.421	1.052
0.500	−8838	−3617	3.263	383	−2.500	0.515	1.029
0.600	−6607	−2371	2.647	189	−1.600	0.609	1.014
0.700	−4671	−1366	2.066	74	−0.900	0.704	1.006
0.800	−2950	−621	1.455	19	−0.400	0.801	1.001
0.900	−1400	−159	0.776	1	−0.100	0.900	1.000
1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Mn(liquid)

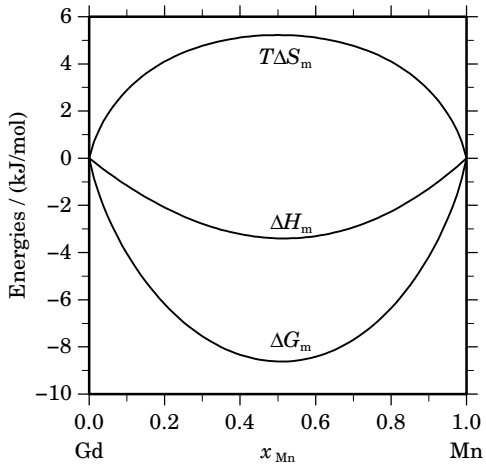

Fig. 2. Integral quantities of the liquid phase at T=1600 K.

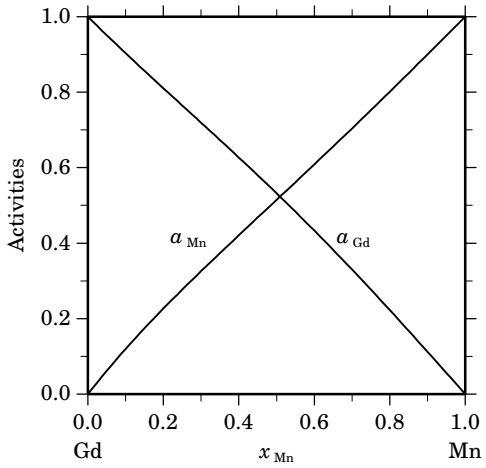

Fig. 3. Activities in the liquid phase at T=1600 K.

Table IV. Standard reaction quantities at 298.15 K for the compounds per mole of atoms.

Compound	x_{Mn}	$\Delta_{\mathrm{f}}G^{\circ}$ / (J/mol)	$\Delta_{\mathrm{f}}H^{\circ}$ / (J/mol)	$\Delta_{\mathrm{f}}S^{\circ}$ / (J/(mol·K))	$\Delta_{\mathrm{f}}C^{\circ}_{P}$ / (J/(mol·K))
Mn_2Gd_1	0.667	−6111	−6408	−0.996	−4.329
$Mn_{23}Gd_6$	0.793	−6026	−6371	−1.158	−2.689
$Mn_{12}Gd_1$	0.923	−3720	−4027	−1.031	−1.003

References

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[1989Nik] I.V. Nikolaenko, V.V. Nosova: Ukr. Khim. Zh. **55** (1989) 1260–1262.
[2001Grö] J. Gröbner, A. Pisch, R. Schmid-Fetzer: J. Alloys Comp. **317-318** (2001) 433–437.