Fe – Mn (Iron – Manganese)

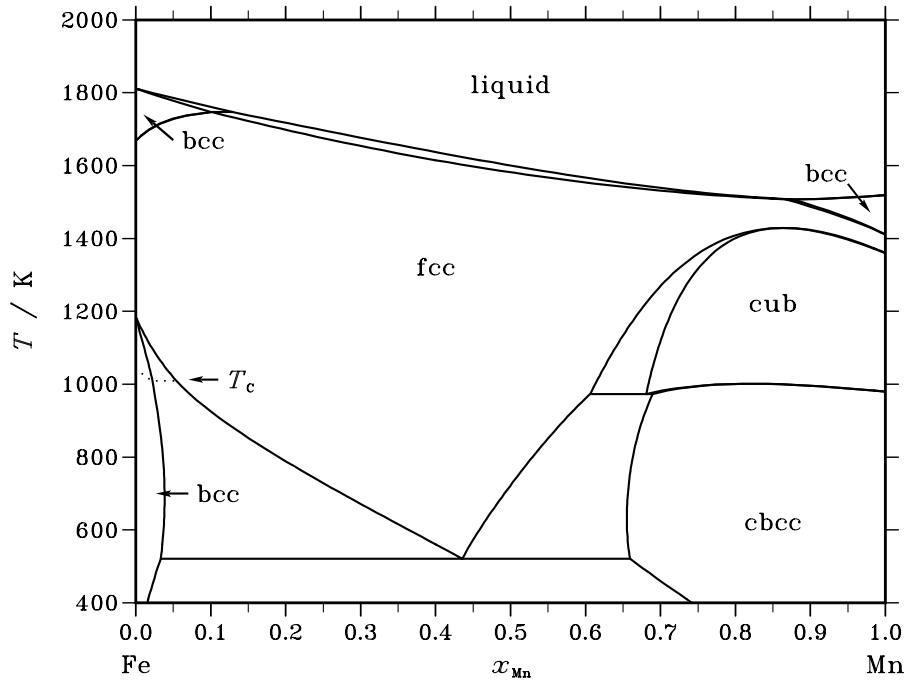

Fig. 1. Calculated phase diagram for the system Fe-Mn.

There is complete solubility in the liquid and fcc phases in the Fe-Mn system. Both elements form bcc before melting but the liquid is more stable in the middle of the system. The low temperature forms of Mn, α-Mn ($A12$) and β-Mn ($A13$) dissolve a large amount of Fe but in the centre of the system the fcc phase is dominating. Mn is a common alloying element in steel, in particular to remove sulphur by forming MnS but also to form work-hardening alloys. The assessment shown here is quite old [89Hua] but it is still the most widely used.

Table I. Phases, structures and models.

Phase	Struktur-bericht	Prototype	Pearson symbol	Space group	SGTE name	Model
liquid					LIQUID	$(Fe,Mn)_1$
bcc	$A2$	W	$cI2$	$Im\overline{3}m$	BCC_A2	$(Fe,Mn)_1$
fcc	$A1$	Cu	$cF4$	$Fm\overline{3}m$	FCC_A1	$(Fe,Mn)_1$
cbcc	$A12$	αMn	$cI58$	$I\overline{4}3m$	CBCC_A12	$(Fe,Mn)_1$
cub	$A13$	βMn	$cP20$	$P4_132$	CUB_A13	$(Fe,Mn)_1$

Table II. Invariant reactions.

Reaction	Type	T / K	Compositions / x_{Mn}			$\Delta_r H$ / (J/mol)
bcc + liquid $\rightleftharpoons$ fcc	peritectic	1746.8	0.100	0.129	0.101	−2328
liquid $\rightleftharpoons$ fcc + bcc	eutectic	1507.2	0.875	0.867	0.877	−12957
fcc $\rightleftharpoons$ cub	congruent	1428.7	0.864	0.864		−1680
cub $\rightleftharpoons$ cbcc	congruent	1001.2	0.820	0.820		−1442
cub $\rightleftharpoons$ fcc + cbcc	eutectoid	973.2	0.681	0.606	0.690	−821
fcc $\rightleftharpoons$ bcc + cbcc	eutectoid	521.3	0.436	0.033	0.659	−2619

Table IIIa. Integral quantities for the liquid phase at 1873 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	−5253	−273	2.659	−191	−0.044	0.000
0.200	−8168	−522	4.082	−376	−0.078	0.000
0.300	−10054	−733	4.976	−541	−0.103	0.000
0.400	−11154	−893	5.478	−673	−0.117	0.000
0.500	−11553	−988	5.641	−759	−0.122	0.000
0.600	−11264	−1003	5.478	−783	−0.117	0.000
0.700	−10246	−926	4.976	−733	−0.103	0.000
0.800	−8388	−742	4.082	−595	−0.078	0.000
0.900	−5418	−438	2.659	−356	−0.044	0.000
1.000	0	0	0.000	0	0.000	0.000

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

Table IIIb. Partial quantities for Fe in the liquid phase at 1873 K.

x_{Fe}	ΔG_{Fe} [J/mol]	ΔH_{Fe} [J/mol]	ΔS_{Fe} [J/(mol·K)]	$G_{\mathrm{Fe}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{Fe}}^{\mathrm{E}}$ [J/(mol·K)]	a_{Fe}	γ_{Fe}
1.000	0	0	0.000	0	0.000	1.000	1.000
0.900	−1641	−10	0.871	−1	−0.005	0.900	1.000
0.800	−3496	−57	1.836	−21	−0.020	0.799	0.999
0.700	−5642	−170	2.922	−88	−0.044	0.696	0.994
0.600	−8184	−376	4.169	−229	−0.078	0.591	0.985
0.500	−11267	−701	5.641	−472	−0.122	0.485	0.970
0.400	−15114	−1175	7.442	−845	−0.176	0.379	0.947
0.300	−20124	−1823	9.771	−1375	−0.240	0.275	0.916
0.200	−27152	−2675	13.069	−2088	−0.313	0.175	0.875
0.100	−38872	−3756	18.749	−3014	−0.396	0.082	0.824
0.000	$-\infty$	−5095	∞	−4179	−0.489	0.000	0.765

Reference state: Fe(liquid)

Table IIIc. Partial quantities for Mn in the liquid phase at 1873 K.

x_{Mn}	ΔG_{Mn} [J/mol]	ΔH_{Mn} [J/mol]	ΔS_{Mn} [J/(mol·K)]	$G_{\mathrm{Mn}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{Mn}}^{\mathrm{E}}$ [J/(mol·K)]	a_{Mn}	γ_{Mn}
0.000	$-\infty$	−2805	∞	−1889	−0.489	0.000	0.886
0.100	−37760	−2643	18.749	−1901	−0.396	0.089	0.885
0.200	−26859	−2381	13.069	−1795	−0.313	0.178	0.891
0.300	−20349	−2048	9.771	−1599	−0.240	0.271	0.902
0.400	−15609	−1669	7.442	−1340	−0.176	0.367	0.918
0.500	−11839	−1274	5.641	−1045	−0.122	0.468	0.935
0.600	−8697	−888	4.169	−742	−0.078	0.572	0.953
0.700	−6013	−541	2.922	−459	−0.044	0.680	0.971
0.800	−3697	−259	1.836	−222	−0.020	0.789	0.986
0.900	−1701	−69	0.871	−60	−0.005	0.897	0.996
1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Mn(liquid)

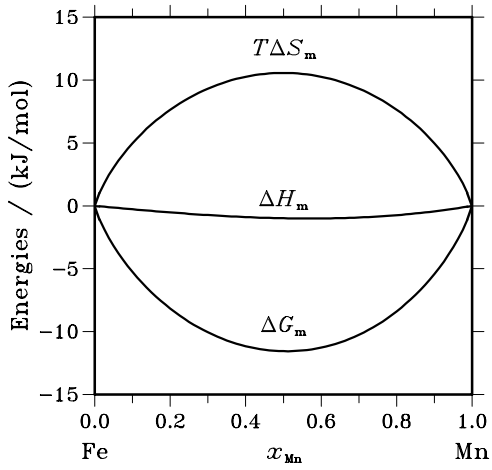

Fig. 2. Integral quantities of the liquid phase at T=1873 K.

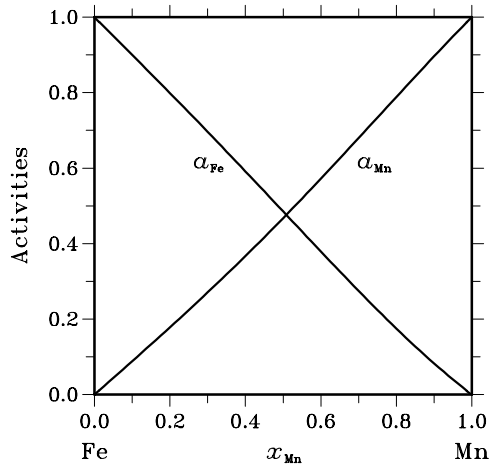

Fig. 3. Activities in the liquid phase at T=1873 K.

Table IVa. Integral quantities for the stable phases at 1273 K.

Phase	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)]
fcc	0.000	0	0	0.000	0	0.000	0.000
	0.100	−3701	−500	2.514	−260	−0.189	0.007
	0.200	−5748	−835	3.860	−452	−0.301	0.019
	0.300	−7043	−1006	4.743	−577	−0.337	0.035
	0.400	−7763	−1015	5.301	−640	−0.295	0.051
	0.500	−7978	−865	5.588	−642	−0.176	0.063
	0.600	−7710	−559	5.618	−587	0.022	0.072
	0.700	−6944	−99	5.377	−478	0.298	0.078
	0.702	−6927	−91	5.370	−476	0.303	0.078
cub	0.735	−6584	−977	4.405	−460	−0.406	0.127
	0.800	−5747	−887	3.818	−450	−0.343	0.096
	0.900	−3745	−559	2.503	−304	−0.200	0.048
	1.000	0	0	0.000	0	0.000	0.000

Reference states: Fe(fcc), Mn(cub)

Table IVb. Partial quantities for Fe in the stable phases at 1273 K.

Phase	x_{Fe}	ΔG_{Fe} [J/mol]	ΔH_{Fe} [J/mol]	ΔS_{Fe} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Fe}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Fe}}$ [J/(mol·K)]	a_{Fe}	γ_{Fe}
fcc	1.000	0	0	0.000	0	0.000	1.000	1.000
	0.900	−1150	−84	0.838	−35	−0.038	0.897	0.997
	0.800	−2498	−330	1.703	−136	−0.153	0.790	0.987
	0.700	−4072	−735	2.621	−297	−0.345	0.681	0.972
	0.600	−5919	−1297	3.631	−512	−0.617	0.572	0.953
	0.500	−8113	−2009	4.794	−776	−0.969	0.465	0.929
	0.400	−10779	−2860	6.221	−1081	−1.398	0.361	0.903
	0.300	−14164	−3841	8.109	−1420	−1.901	0.262	0.874
	0.298	−14227	−3858	8.145	−1426	−1.910	0.261	0.874
cub	0.265	−14227	−1435	10.048	−186	−0.981	0.261	0.983
	0.200	−18017	−2591	12.117	−982	−1.264	0.182	0.911
	0.100	−26701	−4549	17.401	−2330	−1.743	0.080	0.802
	0.000	$-\infty$	−6737	∞	−3836	−2.279	0.000	0.696

Reference state: Fe(fcc)

Table IVc. Partial quantities for Mn in the stable phases at 1273 K.

Phase	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}
fcc	0.000	$-\infty$	−5851	∞	−2960	−2.271	0.000	0.756
	0.100	−26659	−4249	17.604	−2288	−1.541	0.081	0.806
	0.200	−18750	−2852	12.488	−1715	−0.893	0.170	0.850
	0.300	−13975	−1636	9.693	−1232	−0.318	0.267	0.890
	0.400	−10529	−592	7.806	−831	0.187	0.370	0.925
	0.500	−7844	279	6.381	−508	0.618	0.477	0.953
	0.600	−5664	976	5.216	−258	0.969	0.586	0.976
	0.700	−3850	1504	4.206	−75	1.240	0.695	0.993
	0.702	−3823	1511	4.190	−72	1.244	0.697	0.993
cub	0.735	−3823	−811	2.366	−558	−0.199	0.697	0.949
	0.800	−2679	−461	1.743	−317	−0.113	0.776	0.970
	0.900	−1194	−115	0.848	−79	−0.028	0.893	0.993
	1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Mn(cub)

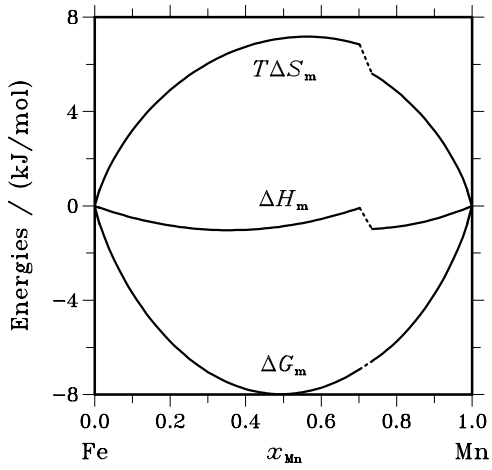

Fig. 4. Integral quantities of the stable phases at T=1273 K.

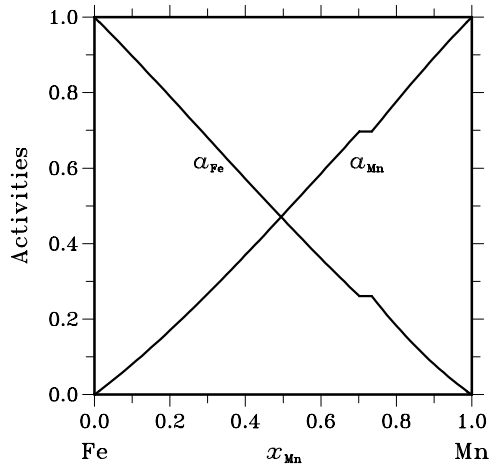

Fig. 5. Activities in the stable phases at T=1273 K.

References

[89Hua] W. Huang: Calphad **13** (1989) 243–252.