Er – Tb (Erbium – Terbium)

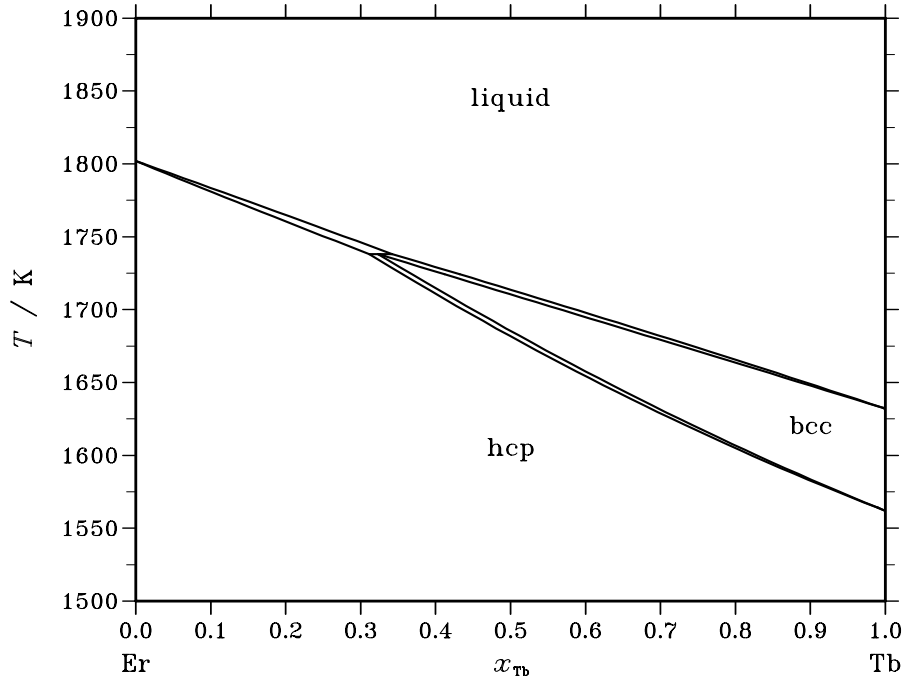

Fig. 1. Calculated phase diagram for the system Er-Tb.

Iron with addition of different rare-earth (RE) elements have attracted attention due to their magnetostrictive properties for building actuators. The analysis of ternary Fe-RE1-RE2 systems is important in order to understand and to optimise synthesis conditions. The binary inter-rare-earth system Er-Tb has been assessed by Norgren [00Nor] based on literature data. Experimental information on solid-liquid equilibria is reported by Spedding *et al.* [73Spe]. They applied metallographic, X-ray and thermal analysis to investigate the system. Complete mutual solubility is observed. The melting point varies with composition almost linearly which makes the two phase equilibrium zone very narrow. The stable structure at low temperature is hcp ($A3$). Lattice parameter measurements vs composition deviate from linearity. The deviation is positive for the a-axis and negative for the c-axis. The bcc phase ($A2$) starts to form at 34 at.% Tb from the melt. The assessment is in good agreement with the experimental data.

Table I. Phases, structures and models.

Phase	Struktur-bericht	Prototype	Pearson symbol	Space group	SGTE name	Model
liquid					LIQUID	$(Er,Tb)_1$
hcp	$A3$	Mg	$hP2$	$P6_3/mmc$	HCP_A3	$(Er,Tb)_1$
bcc	$A2$	W	$cI2$	$Im\overline{3}m$	BCC_A2	$(Er,Tb)_1$

Table II. Invariant reactions.

Reaction	Type	T / K	Compositions / x_{Tb}			$\Delta_{\mathrm{r}}H$ / (J/mol)
hcp + liquid $\rightleftharpoons$ bcc	peritectic	1738.2	0.311	0.342	0.323	-2617

Table IIIa. Integral quantities for the liquid phase at 1850 K.

x_{Tb}	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	−5032	−32	2.703	−32	0.000	0.000
0.200	−7753	−56	4.161	−56	0.000	0.000
0.300	−9470	−74	5.079	−74	0.000	0.000
0.400	−10436	−84	5.596	−84	0.000	0.000
0.500	−10749	−88	5.763	−88	0.000	0.000
0.600	−10436	−84	5.596	−84	0.000	0.000
0.700	−9470	−74	5.079	−74	0.000	0.000
0.800	−7753	−56	4.161	−56	0.000	0.000
0.900	−5032	−32	2.703	−32	0.000	0.000
1.000	0	0	0.000	0	0.000	0.000

Reference states: Er(liquid), Tb(liquid)

Table IIIb. Partial quantities for Er in the liquid phase at 1850 K.

x_{Er}	ΔG_{Er} [J/mol]	ΔH_{Er} [J/mol]	ΔS_{Er} [J/(mol·K)]	$G_{\mathrm{Er}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{Er}}^{\mathrm{E}}$ [J/(mol·K)]	a_{Er}	γ_{Er}
1.000	0	0	0.000	0	0.000	1.000	1.000
0.900	−1624	−4	0.876	−4	0.000	0.900	1.000
0.800	−3446	−14	1.855	−14	0.000	0.799	0.999
0.700	−5518	−32	2.966	−32	0.000	0.699	0.998
0.600	−7913	−56	4.247	−56	0.000	0.598	0.996
0.500	−10749	−88	5.763	−88	0.000	0.497	0.994
0.400	−14220	−126	7.619	−126	0.000	0.397	0.992
0.300	−18691	−172	10.010	−172	0.000	0.297	0.989
0.200	−24980	−224	13.382	−224	0.000	0.197	0.986
0.100	−35702	−284	19.145	−284	0.000	0.098	0.982
0.000	$-\infty$	−350	∞	−350	0.000	0.000	0.978

Reference state: Er(liquid)

Table IIIc. Partial quantities for Tb in the liquid phase at 1850 K.

x_{Tb}	ΔG_{Tb} [J/mol]	ΔH_{Tb} [J/mol]	ΔS_{Tb} [J/(mol·K)]	$G_{\mathrm{Tb}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{Tb}}^{\mathrm{E}}$ [J/(mol·K)]	a_{Tb}	γ_{Tb}
0.000	$-\infty$	−350	∞	−350	0.000	0.000	0.978
0.100	−35702	−284	19.145	−284	0.000	0.098	0.982
0.200	−24980	−224	13.382	−224	0.000	0.197	0.986
0.300	−18691	−172	10.010	−172	0.000	0.297	0.989
0.400	−14220	−126	7.619	−126	0.000	0.397	0.992
0.500	−10749	−88	5.763	−88	0.000	0.497	0.994
0.600	−7913	−56	4.247	−56	0.000	0.598	0.996
0.700	−5518	−32	2.966	−32	0.000	0.699	0.998
0.800	−3446	−14	1.855	−14	0.000	0.799	0.999
0.900	−1624	−4	0.876	−4	0.000	0.900	1.000
1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Tb(liquid)

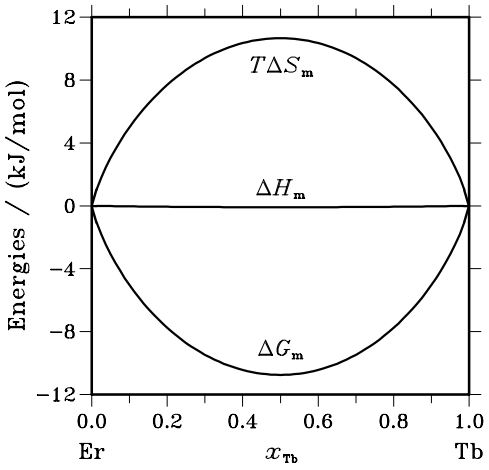

Fig. 2. Integral quantities of the liquid phase at T=1850 K.

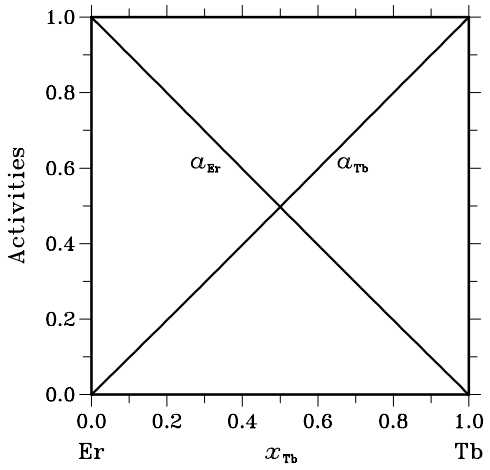

Fig. 3. Activities in the liquid phase at T=1850 K.

Table IVa. Integral quantities for the stable phases at 1500 K.

Phase	x_{Tb}	ΔG_{m} [J/mol]	ΔH_{m} [J/mol]	ΔS_{m} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{m}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{m}}$ [J/(mol·K)]	ΔC_P [J/(mol·K)]
hcp	0.000	0	0	0.000	0	0.000	0.000
	0.100	−4043	12	2.703	12	0.000	0.000
	0.200	−6220	21	4.161	21	0.000	0.000
	0.300	−7591	27	5.079	27	0.000	0.000
	0.400	−8362	31	5.596	31	0.000	0.000
	0.500	−8612	33	5.763	33	0.000	0.000
	0.600	−8362	31	5.596	31	0.000	0.000
	0.700	−7591	27	5.079	27	0.000	0.000
	0.800	−6220	21	4.161	21	0.000	0.000
	0.900	−4043	12	2.703	12	0.000	0.000
	1.000	0	0	0.000	0	0.000	0.000

Reference states: Er(hcp), Tb(hcp)

Table IVb. Partial quantities for Er in the stable phases at 1500 K.

Phase	x_{Er}	ΔG_{Er} [J/mol]	ΔH_{Er} [J/mol]	ΔS_{Er} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Er}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Er}}$ [J/(mol·K)]	a_{Er}	γ_{Er}
hcp	1.000	0	0	0.000	0	0.000	1.000	1.000
	0.900	−1313	1	0.876	1	0.000	0.900	1.000
	0.800	−2778	5	1.855	5	0.000	0.800	1.000
	0.700	−4437	12	2.966	12	0.000	0.701	1.001
	0.600	−6350	21	4.247	21	0.000	0.601	1.002
	0.500	−8612	33	5.763	33	0.000	0.501	1.003
	0.400	−11381	47	7.619	47	0.000	0.402	1.004
	0.300	−14952	64	10.010	64	0.000	0.302	1.005
	0.200	−19989	83	13.382	83	0.000	0.201	1.007
	0.100	−28612	105	19.145	105	0.000	0.101	1.008
	0.000	$-\infty$	130	∞	130	0.000	0.000	1.010

Reference state: Er(hcp)

Table IVc. Partial quantities for Tb in the stable phases at 1500 K.

Phase	x_{Tb}	ΔG_{Tb} [J/mol]	ΔH_{Tb} [J/mol]	ΔS_{Tb} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Tb}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Tb}}$ [J/(mol·K)]	a_{Tb}	γ_{Tb}
hcp	0.000	$-\infty$	130	∞	130	0.000	0.000	1.010
	0.100	−28612	105	19.145	105	0.000	0.101	1.008
	0.200	−19989	83	13.382	83	0.000	0.201	1.007
	0.300	−14952	64	10.010	64	0.000	0.302	1.005
	0.400	−11381	47	7.619	47	0.000	0.402	1.004
	0.500	−8612	33	5.763	33	0.000	0.501	1.003
	0.600	−6350	21	4.247	21	0.000	0.601	1.002
	0.700	−4437	12	2.966	12	0.000	0.701	1.001
	0.800	−2778	5	1.855	5	0.000	0.800	1.000
	0.900	−1313	1	0.876	1	0.000	0.900	1.000
	1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Tb(hcp)

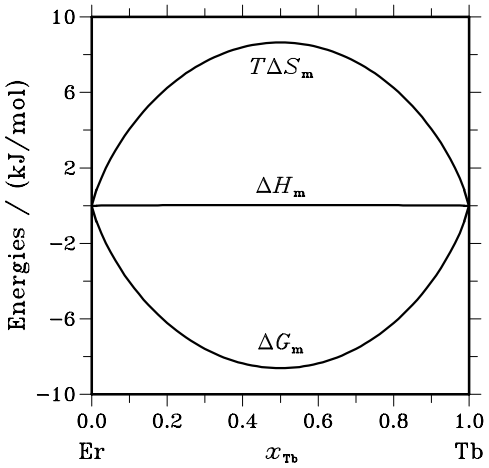

Fig. 4. Integral quantities of the stable phases at T=1500 K.

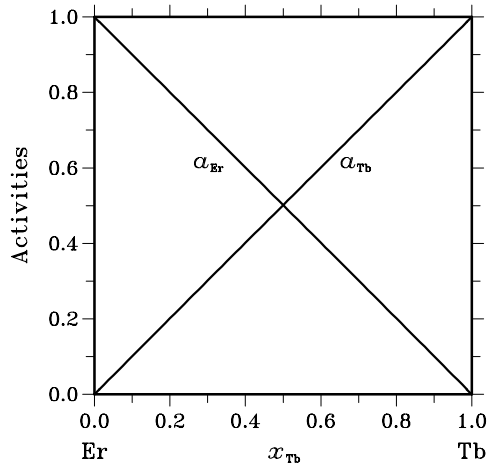

Fig. 5. Activities in the stable phases at T=1500 K.

References

[73Spe] F.H. Spedding, B. Sanden, B.J. Beaudry: J. Less-Common Met. **31** (1973) 1–13.
[00Nor] S. Norgren: J. Phase Equilibria **21** (2000) 148–156.