Aluminium – Cerium – Cobalt

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Literature Data

Critical analysis of the literature data has been carried out by [1991Gri], based on 11 articles, from which the following information could be retrieved: the partial isothermal section at 600°C [1980Zar], composition and structure of several compounds such as $CeCoAl_4$ [1974Yar, 1977Ryk], CeCoAl [1971Oes, 1983Gri], $Ce_2Co_{15}Al_2$ [1962Zar], structure of the phases at 33.3 [1968Man, 1982Eva] and 16.7 at.% Ce ($RCo_{5-x}Al_x$) [1976Zak, 1982Eva], enthalpy of formation of the CeCoAl compound [1987Shi].
Three new works contain the results of investigations concerning crystal structure and magnetic properties of the $CeCoAl_4$ compound [1997Moz] and the $Ce_2Co_{17-x}Al_x$ phase [1999Hu, 1999She1, 1999She2].
The samples were generally prepared by arc melting the pure metals. Both annealed and as cast alloys were investigated. Mainly the X-ray diffraction methods were used for crystal structure determination. Only the $CeCoAl_4$ crystal structure was studied also by neutron diffraction [1997Moz]. Magnetic properties were studied by means of a SQUID magnetometer in the 5-300 K temperature range and in magnetic fields up to 5 T [1997Moz, 1999Hu]. Extracting sample magnetometer in fields up to 65 kOe was used by [1999She1, 1999She2]. Foner magnetometer and Faraday method were used in older works.

Binary Systems

Ce-Co and Al-Ce binary systems were taken from [Mas2]. Al-Co system was accepted from the [2003Gru] assessment.

Solid Phases

Four ternary compounds were found in the system, for all of them the crystal structure has been determined: τ_1, $CeCo_2Al_8$ by [1974Yar], τ_3, $CeCoAl_4$ by [1977Ryk, 1997Moz]. [1962Zar] described the $Ce_2Co_{15}Al_2$ ternary phase. The existence of this phase was confirmed by [1999Hu, 1999She1, 1991She2]. However the stability ranges of the rhombohedral phase significantly differ in these articles: it is $Ce_2Co_{15-14}Al_{2-3}$ according to [1999Hu], and $Ce_2Co_{16-14}Al_{1-3}$ according to [1999She2]. Moreover, in the latter article, at the composition $Ce_2Co_{13-12}Al_{4-5}$ a hexagonal phase similar to $CaCu_5$ was reported. This discrepancy may result from different investigation temperatures (1000°C in [1999She1, 1999She2]). An earlier investigation of the $Ce_{1-x}Co_5Al_x$ composition, annealed at 1000°C, was made by [1982Eva]. It showed that substitution of 1 to 3 at.% Al ($0.06 \le x \le 0.18$) for Ce in $CeCo_5$ produces a mixture of the 1:5 and 2:17 phases; there are two variations of the 2:17 phase which are isostructural with the hexagonal Th_2Ni_{17} type and rhombohedral Th_2Zn_{17} type phases respectively. At the composition $Ce_{0.76}Co_5Al_{0.24}$ (4 at.% Al) the alloy consists of the 2:17 type phases and the metallographic appearance is single phase.
Some uncertainty is with the CeCoAl compound. [1968Man, 1969Tes] adopted for this phase the $MgZn_2$ type structure. Previously [1971Oes] had proposed a different crystal structure, even though [1968Man] reported the presence of an additional phase. [1980Zar] also reports that CeCoAl does not belong to $MgZn_2$ type structure. Complete investigation of the CeCoAl structure using single-crystal technique was performed by [1983Gri]: he determined a monoclinic structure related to $MgZn_2$.
The crystal structure of all the phases included in the investigated part of the system is presented in Table 1.

Isothermal Section

The Al-Ce-Co isothermal section at 600°C is presented in Fig. 1. It is built according to [1980Zar], but modified taking into account new data on the Al-Co system [2003Gru]. The $CeCo_{5-x}Al_x$ phase is reported to exist in the ternary [1976Oes, 1980Zar, 1982Eva] but, at this temperature, it is not stable in the Ce-Co subsystem.

Miscellaneous

In most cases, the magnetic properties of CeCoAl, $CeCoAl_4$ and of the solid solutions based on Ce_2Co_{17}, $CeCo_5$ and $CeCo_2$ were investigated. Only for CeCoAl phase also the enthalpy of formation was measured [1987Shi].

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Table 1: Crystallographic Data of Solid Phases

Phases/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(Al) < 660.452	*cF*4 $Fm\bar{3}m$ Cu	a = 404.88	[Mas2]
(αCo) 1495-422	*cF*4 $Fm\bar{3}m$ Cu	a = 354.46	[Mas2]
(εCo) < 422	*hP*2 $P6_3/mmc$ Mg	a = 250.71 c = 406.95	[Mas2]
Co_2Al_9 < 970	*mP*22 $P2_1/a$ ...	a = 855.6 b = 629.0 c = 621.3 β = 94.76°	[2003Gru]
O-Co_4Al_{13} < 1080	*oP*102 $Pmn2_1$ O-Co_4Al_{13}	a = 815.8 b = 1234.7 c = 1445.2	[2003Gru]
M-Co_4Al_{13} 1093-?	*mC*102 *C2/m* Fe_4Al_{13}	a = 1517.3 b = 810.9 c = 1234.9 β = 107.84°	[2003Gru]
Y 1127-? either (o-Co_4Al_{13}) or (m-Co_4Al_{13})	... *Immm* *mC*34 *C2/m* Os_4Al_{13}	a = 1531.0 b = 1235.0 c = 758.0 a = 1704.0 b = 409.0 c = 758.0 β = 116.0°	[2003Gru]

Phases/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
Z < 1158	C-centr. monocl.	a = 3984.0 b = 814.8 c = 3223.0 β = 107.97°	[2003Gru]
Co_2Al_5 < 1188	*hP*28 *P6$_3$/mmc* Co_2Al_5	a = 767.2 c = 760.5	[2003Gru]
$Co_{1-x}Al_x$ < 1640	*cP*2 *Pm$\bar{3}$m* CsCl	a = 285.7 a = 286.2 a = 285.9	x = 0.52 [2003Gru] x = 0.5 x = 0.43
βCe_3Al_{11} 1235-1020	*tI*10 *I4/mmm* $BaAl_4$	a = 437.4 c = 1012	[Mas2, V-C2]
αCe_3Al_{11} < 1020	*oI*28 *Immm* La_3Al_{11}	a = 439.5 b = 1302.5 c = 1009.2	[Mas2, V-C2]
$CeAl_3$ < 1135	*hP*8 *P6$_3$/mmc* Ni_3Sn	a = 654.1 c = 461.0	[Mas2, V-C2]
$CeAl_{2-x}Co_x$ < 1480	*cF*24 *Fd$\bar{3}$m* $MgCu_2$	 a = 804.73 a = 801.5 ± 2	0 < x < 0.3 at 600°C [1980Zar] x = 0 [1968Man] x = 0.166 [1968Man]
CeAl < 845	*oC*16 *Cmc2* or *Cmcm* CeAl	a = 926.9 b = 768.0 c = 576.1	[1988Gsc]
βCe_3Al 655-250	*cP*4 *Pm$\bar{3}$m* $AuCu_3$	a = 498.9	[1988Gsc]
αCe_3Al < 250	*hP*8 *P6$_3$/mmc* Ni_3Sn	a = 704.2 c = 545.1	[1988Gsc]

Phases/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
$\beta Ce_2Co_{17-x}Al_x$	*hP*38	*a* = 839	*x* = 0 [1976Oes]
1220-~1050	*P6$_3$/mmc*	*c* = 816.3	
	Th_2Ni_{17}	*a* = 838	*x* = 0 [1962Zar] at 500°C
		c = 812	
		a = 838.1	*x* = 0 [1999She2] at 1000°C
		c = 814.0	
		a = 838.8	*x* = 0 [1999Hu] at 1000°C
		c = 814.4	
		a = 840.2	*x* = 1 [1999She2]at 1000°C
		c = 816.4	
	*hP*6	*a* = 846.2	*x* = 3 [1999She2] at 1000°C
	P6/mmm	*c* = 1232.8	
	$CaCu_5$	*a* = 843.0	*x* = 3.5 [1999Hu] at 1000°C two phase
		c = 1235.1	sample (1:5)
		a = 493.3	*x* = 4 [1999Hu] at 1000°C
		c = 411.6	
		a = 494.8	*x* = 5 [1999Hu] at 1000°C
		c = 409.3	
$\alpha Ce_2Co_{17-x}Al_x$	*hR*57	*a* = 837.8	*x* = 0 [Mas2, V-C2]
≲1050	*R$\bar{3}$m*	*c* = 1220.6	
	Th_2Zn_{17}	*a* = 839.7	*x* = 1 [1999Hu]at 1000°C
		c = 1222.7	
		a = 841.1	*x* = 2 [1999Hu] at 1000°C
		c = 1225.4	
		a = 843.4	*x* = 2 [1999She2] at 1000°C
		c = 1228.8	
		a = 843.3	*x* = 3 [1999Hu] at 1000°C
		c = 1230.2	

Phases/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
$CeCo_{5-x}Al_x$	*hP*6		0.03 < *x* < 1.2 at 600°C [1980Zar]
	P6/mmm	*a* = 491.97	*x* = 0 [Mas2, V-C2]
	$CaCu_5$	*c* = 402.9	
$CeCo_5$		*a* = 491.6	*x* = 0 [1976Oes]
1134-600		*c* = 401.2	
		a = 493	*x* = 0, at 600°C
		c = 402	[1980Zar]
		a = 492.92	*x* = 0, at 1000°C
		c = 401.73	[1982Eva]
		a = 492.87 ± 50	*x* = 0.06 ($Ce_{1-x}Co_5Al_x$) [1982Eva]
		c/*a* = 0.815	
		a = 492.92 ± 50	*x* = 0.12 ($Ce_{1-x}Co_5Al_x$) [1982Eva]
		c/*a* = 0.815	
		a = 493.00 ± 50	*x* = 0.18 ($Ce_{1-x}Co_5Al_x$) [1982Eva]
		c/*a* = 0.815	
		a = 492.9	*x* = 0.3 [1976Oes]
		c = 402.2	
		a = 493.8	*x* = 0.6 [1976Oes]
		c = 403.2	
		a = 490.2	*x* = 0.9 [1976Oes]
		c = 410.5	
		a = 491.0	*x* = 1.2 [1976Oes]
		c = 410.4	
		a = 503	*x* = 1.2 [1980Zar]
		c = 407	
Ce_5Co_{19}	*hR*72	*a* = 494.75	[Mas2, V-C2]
< 1134	$R\bar{3}m$	*c* = 4874.34	
	Ce_5Co_{19}		
Ce_2Co_7	*hP*36	*a* = 494.9	[Mas2, V-C2]
< 1130	$P6_3/mmc$	*c* = 2449	
	Ce_2Ni_7		
$CeCo_3$	*hR*36	*a* = 496.4	[Mas2, V-C2]
< 1103	$R\bar{3}m$	*c* = 2481.4	
	$NbBe_3$		
$CeCo_{2-x}Al_x$	*CF*24		0.3 < *x* < 0 [1980Zar]
< 1036	$Fd\bar{3}m$	*a* = 714.67	*x* = 0 [1968Man]
	$MgCu_2$	*a* = 715	*x* = 0 [1980Zar]
		a = 717.6	*x* = 0.167 [1968Man]
		a = 719	*x* = 0.3 [1980Zar]
$Ce_{24}Co_{11}$	*hP*70	*a* = 958.7	[V-C2]
	$P6_3mc$	*c* = 2182.5	
	$Ce_{24}Co_{11}$		
* τ_1, $CeCo_2Al_8$	*oP*44	*a* = 1241	[1974Yar, 1980Zar]
	Pbam	*b* = 1430	
	$CeFe_2Al_8$	*c* = 412	

Phases/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
* τ_2, $Ce_2Co_{15}Al_2$	*hR*57	*a* = 844	[1962Zar]
	$R\bar{3}m$	*c* = 1230	
	Th_2Zn_{17}	*a* = 844	[1980Zar]
		c = 1250	
* τ_3, $CeCoAl_4$	*oC*12	*a* = 770.1	[1977Ryk]
	Pmma	*b* = 408.2	
	$LaCoAl_4$	*c* = 702.3	
		a = 7589	[1980Zar]
		b = 404.8	
		c = 701.4	
		a = 766.024	[1997Moz]
		b = 405.616	
		c = 691.355	
* τ_4, CeCoAl	*hP*12	*a* = 514.0	[1969Tes]
	$P6_3/mmc$	*c* = 800.0	
	$MgZn_2$	*a* = 549.0	[1968Man]
		c = 866.0	
	*mC*12	*a* = 1109.8(7)	(related to $MgZn_2$) [1983Gri]
	C2/m	*b* = 441.0(1)	
	$PdBi_2$	*c* = 480.7(3)	
		α = 104.61(5)°	

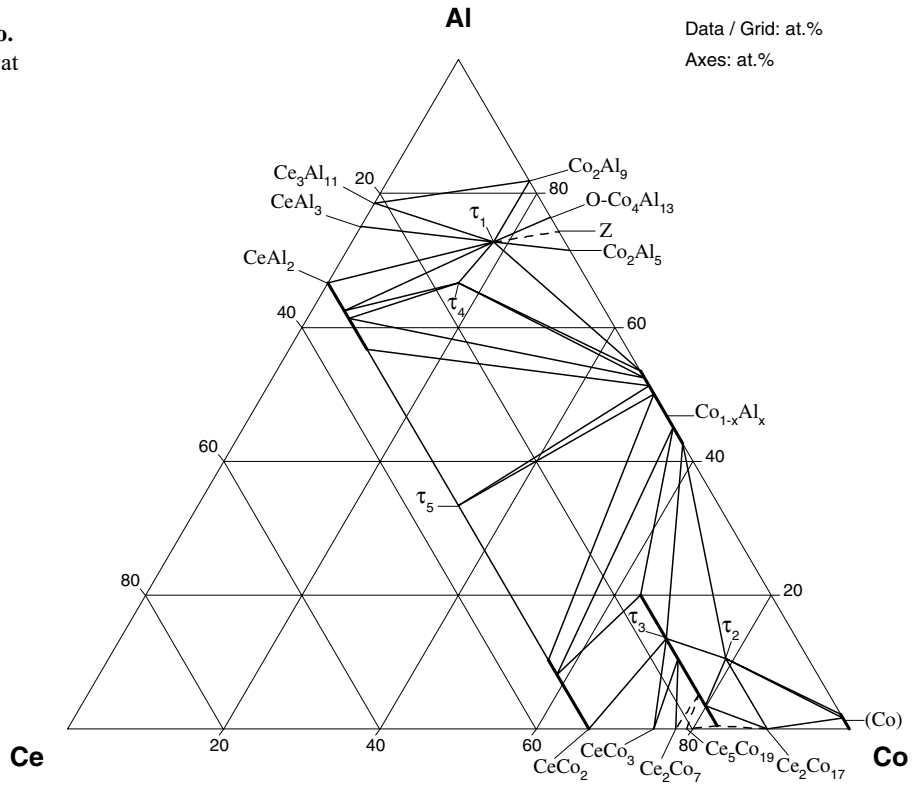

Fig. 1: Al-Ce-Co. Isothermal section at 600°C