Aluminium – Cobalt – Yttrium

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Literature Data

A critical analysis of the literature data on the Al-Co-Y system was made by [1991Gri] based on articles published in the period 1971 to 1990. These investigations have generated isothermal sections of the phase diagram [1971Ryk] and determined compositions and crystal structures of 4 ternary compounds: $YCoAl_{4-x}$, $YCoAl_2$, YCoAl and ~YCo_2Al_7 by [1971Ryk, 1972Ryk]. Several papers were devoted to alloys from the solid solution regions based on binary compounds of the Co-Y system: $Y_2(Co_{1-x}Al_x)_{17}$ in papers by [1971Ryk, 1974Ham, 1985Mod] and $Y(Co_{1-x}Al_x)_5$ by [1971Ryk, 1982Chu1, 1982Chu2, 1985Yos]. During the last 15 years 10 more articles on this system were published with focus on the crystal structure and alloys from the solid solution regions as well as on the ternary compounds. [1992Gla] re-assessed the composition and structure of the $YCoAl_4$ phase to be: $Y_2Co_3Al_9$; and in [2001Rou] its magnetic properties were examined. The interest in the properties of the alloys from the solid solution regions remains: $Y_2(Co_{1-x}Al_x)_{17}$ [1997Zha, 1999She], $Y(Co_{1-x}Al_x)_5$ [1996Tha, 2002Zlo] and $Y(Co_{1-x}Al_x)_2$ [1993Tov, 1998Got, 1991Gab, 1999Mus, 2000Mus].
The samples usually were prepared by arc melting high purity metals under argon atmosphere. Then they were heat treated at various temperatures and investigated both in annealed and in as cast state, predominantly using X-ray methods. Magnetic properties were examined using SQUID magnetometer in a temperature range of 2-300 K and in magnetic fields up to 7 T. Neutron diffraction was applied by [2002Zlo]. Single crystal of the YCo_4Al composition has been successfully grown in a tri-arc Czochralski apparatus by [1996Tha] and sizable single crystals of $Y_2(Co,Al)_{17}$ were produced by [1985Mod] in Bridgman technique.

Binary Systems

Co-Y binary system was taken from [Mas2]. Al-Co system was accepted according to [2003Gru] and Al-Y as published by [2003Cor].

Solid Phases

Four ternary compounds were found and stability regions and structure of YCoAl compound was determined in [1971Ryk, 1972Ryk]. The complete determination of $YCoAl_2$ crystal structure is due to [1971Ryk, 1973Ryk]. The composition of ~$YCoAl_4$ phase was re-assessed as being $Y_2Co_3Al_9$ and its structure completely calculated by [1992Gla]. The structural symmetry and lattice parameters of ~YCo_2Al_7 is available from [1971Ryk], but the structure itself is still unknown. The change of the lattice parameters in the homogeneity region of the $Y(Co_{1-x}Al_x)_2$ solid solution is shown in Fig. 1 according to the data by [1985Yos, 1999Mus]. For alloys in the $Y_2(Co_{1-x}Al_x)_{17}$ solid solution, annealed at 1150°C, the change of lattice parameters with changing Co/Al concentration is given in the Fig. 2 [1974Ham].
[1997Zha] and co-authors reported the crystal structures for $Y_2Co_{17-x}Al_x$ (x = 2, 3) and have found that samples of such compositions, annealed for 3 weeks at 900°C, are single phase and belong to the Th_2Zn_{17} type structure. Lattice parameters were not presented. Table 1 summarizes the composition and structure data of the solid phases in the system Al-Co-Y.

Isothermal Sections

Phase configurations at 600°C in the partial isothermal section, Fig. 3, are drawn to merge consistently the data from [1971Ryk] with the newly evaluated data on the Al-Co system and the re-assessed compositions of the compounds. Both groups of authors, [1971Ryk, 1996Tha, 2002Zlo] investigating the $YCo_{5-x}Al_x$ region and [1971Ryk, 1974Ham, 1999She] investigating the $Y_2Co_{17-x}Al_x$ solid solutions reported the presence of the phases with $CaCu_5$ and Th_2Ni_{17} type structures, which is in conflict with the binary Co-Y data. At that point it is not clear whether these results are more correct than the information presented in [Mas2], because the temperature for the polymorphic transformation $\beta Y_2Co_{17} \rightleftharpoons \alpha Y_2Co_{17}$ is not well defined as is the decomposition temperature of YCo_5.

Notes on Materials Properties and Applications

Weakly itinerant ferromagnetism has been found in the magnetically dilute system $Y(Co_{1-x}Al_x)_2$ (x = 0.13 ~ 0.19) [1985Yos]. The temperature dependence of the first magneto-crystalline anisotropy constant K1 has been deduced for $Y(Co_{0.85}Al_{0.15})_2$ samples [1993Tov]. The magnitude of K_1 is equal to 7.6×10^4 erg cm^{-3} at T = 7 K and falls rapidly with increasing temperature. K_1 has a negative sign over the temperature range investigated from 7 to 20 K, i.e. below T_C = 25 K [1993Tov]. In the concentration region $0.12 < x < 0.15$ a meta-magnetic transition from the weakly developed ferromagnetic to a stronger ferromagnetic was observed by [1998Got]. The critical field of this transition B_C was found to increase with pressure at a rate of dB_C/dP = 7.8 GPa^{-1} for x = 0.075. For x = 0.09 B_C increases at a rate of dB_C/dP = 7.4 GPa^{-1}. The initial volume compressibility amounts up to 8.7×10^{-3} GPa^{-1} at 77 K [1999Mus].
The magnetic properties of alloys from the $Y_2(Co_{1-x}Al_x)_{17}$ phase field were investigated by [1974Ham, 1997Zha, 1999She]. When the Al content increases the Curie temperature and saturation magnetization decrease [1974Ham, 1999She]; also the magneto-crystalline anisotropy reverses from easy-plane to easy-axis anisotropy for higher Al concentration [1997Zha]. In the $Y(Co_{1-x}Al_x)_5$ solid solution, similarly to $Y_2(Co_{1-x}Al_x)_{17}$, the Co substitution of Co by Al reduces the Curie temperature, saturation magnetization and changes the magneto-crystalline anisotropy [2002Zlo]. The single crystal investigation of YCo_4Al shows that Al substitution also leads to a large decrease of the Co magnetic moment compared with YCo_5 [1996Tha]. A magnetization anisotropy of 3.4% has been found for YCo_4Al [1996Tha]. $Y_2Co_3Al_9$ compound is a Pauli paramagnet [2001Rou].

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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) 422-1495	*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-?	*oI** *Immm* or *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]
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
αYAl_3 < 645(?)	*hP*8 $P6_3/mmc$ Ni_3Sn	*a* = 627.6 ± 2 *c* = 458.2 ± 1	[2003Cor] Metastable phase
βYAl_3 980-655	*hP*36 $R\bar{3}m$ $BaPb_3$	*a* = 620.4 ± 2 *c* = 2118.4 ± 2	[2003Cor]

Phases/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
$Y(Co_xAl_{1-x})_2$	*cF*24	*a* = 785.5 ± 7	*x* = 0 [2003Cor]
< 1485	$Fd\bar{3}m$	*a* = 784	*x* = 0 [1971Ryk]
	$MgCu_2$	*a* = 788 to 786	supersaturated
		a = 771	*x* = 0.3 [1971Ryk]
αY_2Co_{17}	*hP*57	*a* = 835.6	[Mas2, V-C2]
< 1300	$R\bar{3}m$	*c* = 1220	
	Th_2Zn_{17}		
$\beta Y_2(Co_{1-x}Al_x)_{17}$	*hP*38	*a* = 835.5	*x* = 0 [Mas2, V-C2]
1357-1300	$P6_3/mmc$	*c* = 812.8	
	Th_2Ni_{17}	*a* = 836	*x* = 0, at 600°C [1971Ryk]
		c = 816	
		a = 835	*x* = 0, at 1500°C [1974Ham]
		c = 812	
		a = 839.6	*x* = 0.11 ($Y_2Co_{15}Al_2$) annealed at
		c = 818.5	1000°C [1999She]
		a = 838	*x* = 0.11 ($Y_2Co_{15}Al_2$),
		c = 819	at 600°C [1971Ryk]
$Y(Co_{1-x}Al_x)_5$	*hP*6	*a* = 495.1	*x* = 0 [Mas2, V-C2]
< 1345	$P6/mmm$	*c* = 397.5	
	$CaCu_5$	*a* = 500	*x* = 0, at 600°C [1971Ryk]
		c = 400	
		a = 498.5	*x* = 0.2 (YCo_4Al) [1996Tha]
		c = 401.9	
		a = 499.8 ± 1	*x* = 0.2 (YCo_4Al) [2002Zlo]
		c = 401.9 ± 1	
		a = 498.3 ± 5	*x* = 0.2 (YCo_4Al) at 2 K [2002Zlo]
		c = 402.4 ± 5	
		a = 504	*x* = 0.36 ($YCo_{3.2}Al_{1.8}$),
		c = 404	at 600°C [1971Ryk]
Y_2Co_7	*hP*54	*a* = 500	[Mas2, V-C2]
< 1320	$R\bar{3}m$	*c* = 3615	
	Er_2Co_7		
YCo_3	*hP*36	*a* = 502.0	[Mas2, V-C2]
< 1308	$R\bar{3}m$	*c* = 2440	
	$NbBe_3$		
?			
	*hP*24	*a* = 501.5	[V-C2]
	$P6_3/mmc$	*c* = 1628	
	$CeNi_3$		
$Y(Co_{1-x}Al_x)_2$	*cF*24	*a* = 721.8	*x* = 0 [Mas2, V-C2]
< 1154	$Fd\bar{3}m$	*a* = 722	*x* = 0 [1971Ryk]
	$MgCu_2$	*a* = 728	*x* = 0.1 [1971Ryk]
τ_1, YCo_2Al_7	orthor.	*a* = 410	[1971Ryk]
		b = 1690	
		c = 1195	

Phases/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
τ_2, $Y_2Co_3Al_9$	*oC*56 *Cmcm* $Y_2Co_3Ga_9$	a = 1276 b = 739 c = 939 a = 1274.0 ± 2 b = 746.35 ± 9 c = 932.1 ± 1 a = 1274.0 ± 5 b = 752.3 ± 8 c = 941.1 ± 3	[1971Ryk] [1992Gla] [2001Rou]
τ_3, $YCoAl_2$	*oC16* $MgCuAl_2$	a = 408 b = 1015 c = 706	[1971Ryk, 1973Ryk]
τ_4, $YCo_{1+x}Al_{1-x}$	*hP*12 $P6_3/mmc$ $MgZn_2$	a = 539 c = 867 a = 536 c = 863	x = 0 (YCoAl) [1971Ryk, 1972Ryk] x = 0.35 ($YCo_{1.35}Al_{0.65}$) [1971Ryk]

Fig. 1: Al-Co-Y. Concentration dependence of the lattice constant of $Y_2(Co_{1-x}Al_x)$ at 1500°C [1974Ham]

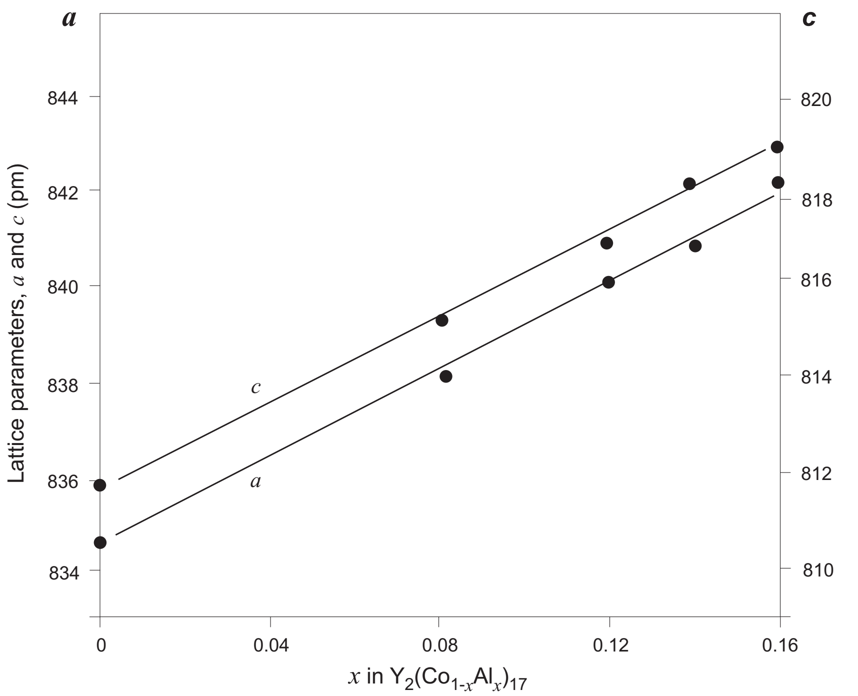

Fig. 2: Al-Co-Y. Concentration dependence of the lattice constant of $Y(Co_{1-x}Al_x)_2$ [1999Mus]

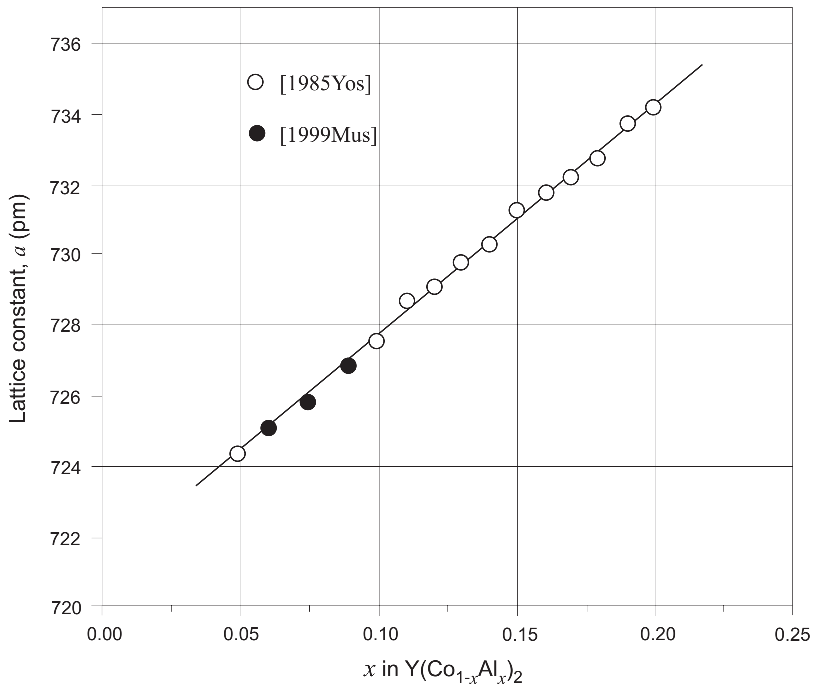

Fig. 3: Al-Co-Y. Isothermal section at 600°C