Aluminium – Cerium – Iron

Bernd Grieb, updated by Alexander Pisch

Literature Data

The first investigation in this ternary system was made in 1925 by Meißner [1925Mei] to describe the "clear-cross method" of Guertler in practical examples when Ce is added to Al-Fe alloys. [1969Zar] examined the ternary system with 106 alloys from 0 to 33.3 at.% Ce using X-ray structural analysis. [1988Sok] studied the phase behavior of 75 to 100 at.% Al at 550°C using X-ray structural analysis. An isothermal section for the Al-rich corner at the same temperature is presented by [1992Rae] without specifying sample preparation details and the purity of the starting materials. Their results are in good agreement. Solid solutions of Al in binary Ce-Fe phases became of interest with a view to obtaining a material with good permanent magnetic properties after the discovery of rare-earth metal (R)-transition metal (TM) magnets. [1985Fra] published lattice parameters and magnetic properties of alloys along $CeFe_2$-$CeAl_2$. [1998Kuc, 2000Kny] measured the structural, magnetic and optical properties of a $Ce_2Fe_{15.3}Al_{1.7}$. Samples were prepared by levitation melting in an induction furnace, annealed at 1000°C for 8h and analyzed by X-ray diffraction and a vibrating sample magnetometer. No information of the purity of the starting material is given. The structural and magnetic properties of $RE_2Fe_{17-x}Al_x$ phases have been reviewed and compared by [2002Ram] A new ternary phase with the composition $Ce_6Fe_{11}Al_3$ has been discovered recently [1992Hu]. The sample has been prepared by melting the elements (Ce,Fe 3N purity, Al 5N) followed by an anneal for 120h at 600 - 800°C wrapped in Mo foil and sealed in quartz. The water quenched samples have been investigated by XRD and Mössbauer spectroscopy to determine the magnetic properties. The structure and magnetic properties of $CeFe_2Al_8$ have been studied by low temperature neutron diffraction [2001Kol] and Mössbauer spectroscopy by [2000Tam, 2001Kol]. No magnetic ordering of this compound has been detected. Ce enhances the mechanical properties of Fe-Al alloys. Because of the very limited solid solubility of transition metals and rare-earth elements in Al rapid solidification processing of Al alloys with Fe and Ce is necessary to avoid intermetallic compounds. [1986Ang, 1986Fie, 1986Jha, 1987Yan, 1988Aye, 1988Sok, 1998Fas, 2000Cha, 2002Zha] produced and investigated rapidly solidified Al-Ce-Fe alloys and found besides binary Fe-Al phases, stable and metastable ternary phases. Enthalpies of formation of three-component liquid alloys were published by [1984Esi].
This evaluation proceeds that of [1991Gri] and integrates the substantial amount of data published since then.

Binary Systems

The Al-Fe binary system has been taken from[2003Pis]. [1996Sac] revised the Al-Ce system and their diagram is accepted. The Al-rich compound in the Al-Ce system, previously reported as $CeAl_4$, is now known to have the Ce_3Al_{11} stoichiometry. The composition $CeAl_4$ taken by [1969Zar] is corrected to Ce_3Al_{11} in the ternary evaluation and in Fig. 1. Ce-Fe is accepted from [Mas].

Solid Phases

The ternary phase $CeFe_4Al_8$ (τ_1) has been studied in detail [1961Gla, 1962Zar, 1969Zar, 1974Viv, 1976Bus]. [1969Zar] found additionally the ternary phases $CeFe_2Al_{10}$ (τ_2), $CeFe_2Al_7$, $CeFe_{1-1.4}Al_{1-0.6}$ and a solid solution of Al in the binary Ce_2Fe_{17} compound with a maximum Al-content of about 60 at.% and having a Th_2Ni_{17} type structure. $CeFe_2Al_{10}$ (τ_2) is iso-structural to $YbFe_2Al_{10}$ [1998Thi]. The lattice parameters of the τ_3 $Ce_6Fe_{11}Al_3$ ternary compound has been determined by [1992Hu]. This compound has a $La_6Fe_{11}Ga_3$ type structure. The structures of $CeFe_2Al_7$, and $CeFe_{1-1.4}Al_{1-0.6}$ were not determined. The ternary phase $CeFe_2Al_7$ is possibly identical to τ_1 $CeFe_2Al_8$, observed and investigated by [1974Yar]. According to [1971Oes], the compounds of the composition RFeAl with light rare-earths show a two phase region of *cF*24 ($MgCu_2$) type together with an unidentified second phase, as opposed to all alloys RFeAl

with heavy rare-earths which form a single phase of the hexagonal *hP*12 ($MgZn_2$) structure type. The formation of successive types of the Laves phase family in the pseudobinary system RFe_2-RAl_2 seems to be connected with Fermi surface-Brillouin zone interactions. It is not completely understood, however, why this does not hold for light and heavy rare-earth elements together, but it is likely that the larger size and higher valencies of the former may contribute to their exceptional behavior. [1985Fra] suggests that the solubility limit for the formation of the pure $MgCu_2$ type structure for $Ce(Fe_{1-x}Al_x)_2$ may be placed near $x = 0.125$. [1986Ang] found five dispersed phases in the as-extruded Al-8.8Fe-3.7Ce and Al-8.9Fe-6.9Ce alloys; metastable $FeAl_6$, two metastable Al-Ce-Fe phases and the equilibrium phases Fe_4Al_{13} and $CeFe_2Al_{10}$. The unit cell of one of the metastable ternary phases was observed as orthorhombic. [1987Yan] produced a metastable icosahedral phase in rapidly cooled Al-8.8Fe-3.3Ce. In addition [1988Aye] found two compounds τ_2 $CeFe_2Al_{10}$ and $CeFe_5Al_{20}$ in the as-extruded conditions. $CeFe_5Al_{20}$ is described as decagonal quasicrystal. The known structure types and crystal parameters of all described solid phases are listed in Table 1. The ternary phase $CeFe_2Al_8$ listed by [V-C] with the source [1980Zar] is not described in the latter paper. [1980Zar] investigated the phase $CeCo_2Al$ with structure type $CeFe_2Al_8$. The lattice parameters in [V-C] are those of $CeCo_2Al_8$.

Invariant Equilibria

The formation of τ_2 follows the peritectic reaction $Ce_3Al_{11}+L \rightleftharpoons \tau_2$. The formation temperature is 940°C [1988Sok].

Isothermal Sections

The investigation of [1925Mei] is rather sketchy and incorrect in the region up to 33.3 at.% Ce. The results of [1969Zar] confirmed several ternary compounds and solid solution of Al in Ce_2Fe_{17}. Figure 1 shows the phase equilibria of the ternary system at 500°C with a maximum Ce content of 33.3 at.%. $CeFe_2$ is printed by [1969Zar] as α phase with no Al solubility. This is corrected in the figure after the results of [1985Fra]. The phase, $CeFe_{1-1.4}Al_{1-0.6}$, detected by [1969Zar] is plotted, but it is necessary to point out the conflict with the results of [1971Oes] as described above. The phase $CeFe_2Al_7$ of [1969Zar] is printed with the composition τ_1 $CeFe_2Al_8$ as in [1974Yar]. At 550°C for Al concentration of 75 to 100 at.% [1988Sok] found the two-phase regions Al+τ_2', Al+$FeAl_3$, Al+Ce_3Al_{11} and the tree phase regions Al+τ_2+$FeAl_3$ and Al+τ_2+Ce_3Al_{11}. The ternary compound is not observed in quenched material. The isothermal section in the Al-rich corner at 550°C as presented by [1992Rae] is identical to Fig. 1.

Temperature – Composition Sections

[1988Sok] published two isopleths. One describes the section between Ce_3Al_{11} and Fe_4Al_{13}, the second between Al and $CeFe_2Al$ (Fig. 2). The isopleth is taken only partially because the shape of the lines with less than 97.8 at.% Al is estimated. The results are based on thermal analysis. The isopleth between Ce_3Al_{11} and Fe_4Al_{13} is not accepted because of inconsistency with the accepted binary Al-Ce.

Notes on Materials Properties and Applications

Magnetic properties of τ_2 $CeFe_4Al_8$ samples have been determined and analyzed by [1998Sch, 2000Hag, 2000Sik, 2001Gac] using neutron diffraction, specific heat and Mössbauer measurements. The magnetic properties of a series of $Ce_2Fe_{17-x}Al_x$ solid solutions with x equal to 0.0, 0.88, 2.06, 2.80, 3.98, 5.15, 6.08, 7.21, 8.20, 9.08, 9.84, and 10.62 have been studied by magnetic measurements, neutron diffraction, and Mössbauer spectroscopy by [1996Mis] and with $8 \leq x \leq 13$ by susceptibility, magnetization and heat capacity measurements by [2000Kon]. The Curie temperature increases from 238 K in Ce_2Fe_{17} to a maximum of 284 K in $Ce_2Fe_{14}Al_3$. The $Ce_2Fe_{17-x}Al_x$ solid solutions behave as spin glasses for x greater than 7 [1996Mis]. The magnetic moment of $Ce_2Fe_{15.3}Al_{1.7}$ has been measured as $M_s = 25.68$ μ_B [2001Kny]. The origin for the magnetism of τ_2 $CeFe_2Al_{10}$ is the mixed Ce^{3+}/Ce^{4+} valence [1998Thi]. $Ce(Fe,Al)_2$ with an aluminium content of 6 at.% has a Curie temperature of 160K and a Néel temperature of 136K [1997Fer]. The hydrogen storing capabilities of $Ce(Fe,Al)_2$ have been investigated by [1997Spa],

their magnetic properties by [1997Fer]. [2000Cha] investigated $Ce(Fe_{1-x}Al_x)_2$ samples with X-ray absorption spectroscopy (XAS) and confirmed the mixed valence of Ce upon Fe substitution to be the origin of the anomalous magnetic behavior in this alloy.

References

[1925Mei] Meissner, K.L. "Some Examples of the Practical Use of the Clear-Cross Method" (in German), *Metall und Erz.*, **22**, 243-247 (1925) (Experimental, Equi. Diagram, 9)

[1958Tay] Taylor, A., Jones, R.M., "Constitution and Magnetic Properties of Iron-Rich Iron-Aluminium Alloys", *J. Phys. Chem. Solids,* **6**, 16-37 (1958) (Crys. Structure, Experimental)

[1961Lih] Lihl, F., Ebel, H., "X-Ray Examination fo the Constitution of Iron-Rich Alloys of the Iron-Aluminium System" (in German), *Arch. Eisenhuettenwesen,* **32**, 483-487, (1961) (Crys. Structure, Experimental)

[1961Gla] Gladyshevsky, E.I., Zarechnyuk, O.S., Teslyuk, M.Yu., Zarechnyuk, O.S., Kuz'ma, Yu.B., "Crystal Structures of some Intermetallic Compounds" (in Russian), *Kristallografiya*, **6**, 267-268 (1961) (Experimental, Crys. Structure, 11)

[1962Zar] Zarechnyuk, O.S., Zarechnyuk, O.S., "The Crystal Structure of Ternary Compounds in the System Ce-Transition Metal-Al" (in Russian), *Kristallografiya,* **7**, 543-554 (1962) (Experimental, Crys. Structure, 9)

[1969Zar] Zarechnyuk, O.S., Mys'kiv, M.G., Ryabov, V.R., "X-Ray Diffraction Study of the Phase Composition of Ce-Fe-Al Alloys Containing up to 33.3 at.% Ce", translated from *Izv. Akad. Nauk SSSR, Met.*, **2**, 164-166 (1969) (Experimental, Crys. Structure, Equi. Diagram, #, *, 9)

[1971Oes] Oesterreicher, H., "Structural Studies of Rare-Earth Compounds RFeAl", *J. Less-Common Met.*, **25**, 341-342 (1971) (Experimental, Crys. Structure, 6)

[1974Viv] Vivchar, O.I., Zarechnyuk, O.S., "Compounds with the $ThMn_{12}$ type Structure in R-Fe-Al Systems" (in Russian), *Tezisy Dokl. Vses. Konf. Kristallokhim.,* Rykhal, R.M., (Ed.), "Intermetalicheskie Soedineniya", **2**nd, 41, (1974) (Experimental, Crys. Structure, 0)

[1974Yar] Yarmolyul, Ya.P., Rykhal, R.M., Zarechnyuk, O.S., "Crystal Structure of $CeFe_2Al_8$ and $LaCoAl_4$" (in Russian), *Tezisy Dokl. Vses. Konf. Kristallokhim.,* Rykhal, R.M., (Ed.), "Intermetalicheskie Soedineniya", **2**nd, 39-40 (1974) (Experimental, Crys. Structure, 0)

[1976Bus] Buschow, K.H.J., van Vucht, J.H.N., van den Hoogenhof,W.W., "Note on the Crystal Structure of the Ternary Rare-Earth-3d Transition Metal Compounds of the Type RT_4Al_8", *J. Less-Common Met.*, **50**, 145-150 (1976) (Experimental, Crys. Structure, 2)

[1980Zar] Zarechnyuk, O.S., Rykhal, R.M., Korin, V.V., "X-Ray Study of the Cerium-Cobalt-Aluminium Ternary System Alloys in the Range of 0 to 33.3 at.% of Cerium" (in Russian), *Dop. Akad. Nauk Ukrain. RSR, Ser. A. Fiz.-Mat. Tekh. Nauki*, **42**, 84-85 (1980) (Experimental, Crys. Structure, 8)

[1984Esi] Esin, Yu.O., Pletneva, E.D., Ermakov, E.D., Valishov, M.G., "Enthalpy of Formation of Three-Component Liquid Alloys Fe-Ce-Si and Fe-Ce-Al" (in Russian), *Izv. VUZ Chern. Metall.*, **12**, 1-4 (1984) (Experimental, Thermodyn., 15)

[1985Fra] Franceschini, D.F., da Cunha, S.F., "Magnetic Properties of $Ce(Fe_{1-x}Al_x)_2$ for $x \leq 0.20$", *J. Magn. Magn. Mater.*, **51**, 280-290 (1985) (Experimental, Crys. Structure, Magn. Prop., 13)

[1986Ang] Angers, L., "Particle Coarsening in Rapidly Solidified Al-Fe-Ce Alloys", *Diss. Abstr. Int.*, **46**, 288 (1986) (Experimental, Crys. Structure, 0)

[1986Fie] Field, R.D., Zindel, J.W., Fraser, H.L., "The Intercellular Phase in Rapidly Solidified Alloys Based on the Al-Fe System", *Scr. Metall.*, **20**, 415-418 (1986) (Experimental, Crys. Structure, 8)

[1986Gri] Griger, A., Syefaniay, V., Turmezey T., "Crystallographic Data and Chemical Compositions of Aluminum-Rich Al-Fe Intermetallic Phases", *Z. Metallkd.*, **77**, 30-35 (1986) (Equi. Diagram, Crys. Structure, Experimental)

[1986Jha] Jha, S.C., Sanders, Jr., T.H., "Microstructure of Melt-Spun Al-Fe and Al-Fe-Ce Alloys", The Metallurgical Society/AIME, Warrendale, Pennsylvania 15086, USA, 243-254 Accession Number: **86**(12), 72-498 (1986)

[1987Yan] Yang, L.Y., Zhao, J.G., Zhan, W.S., "Icosahedral Phase in Rapidly Cooled Al-Fe-Ce Alloy", *J. Phys. F: Met. Phys.*, **17**, L97-L99 (1987) (Experimental, Crys. Structure, 13)

[1988Aye] Ayer, R., Angers, L.M., Mueller, R.R., Scanlon, J.C., Klein, C.F., "Microstructural Characterization of the Dispersed Phases in Aluminium-Cerium-Iron System", *Metall. Trans. A*, **19A**, 1645-1656 (1988) (Experimental, Crys. Structure, Equi. Diagram, 17)

[1988Gsc] Gschneidner, Jr. K.A., Calderwood, F.W., "The Aluminum-Cerium (Al-Ce) System", *Bull. Alloy Phase Diagrams*, **9**, 669-672, (1988) (Equi. Diagram, Review, 35)

[1988Sok] Sokolovskaya, E.M., Kazakova, E.F., Filippova, A.A., "Phase Diagrams of Equilibrium and Fast-Quenched Al-Fe-Ce Alloys", *Russ. Metall*., 1988 (2), 201-203 1988, translated from *Izv. Akad. Nauk SSSR, Met.*, **2**, 209-210 (1988) (Experimental, Crys. Structure, Equi. Diagram, #, *, 3)

[1991Gri] Grieb, B., "Aluminium - Cerium - Iron", MSIT Ternary Evaluation Program, in *MSIT Workplace*, Effenberg, G. (Ed.), MSI, Materials Science International Services GmbH, Stuttgart; Document ID: 10.16414.1.20, (1991) (Crys. Structure, Equi. Diagram, Assessment, 17)

[1992Hu] Hu, B.P., Coey, J.M.D., Klesnar, H., Rogl, P., "Crystal Structure, Magnetism and ^{57}Fe Moesbauer Spectra of Ternary $RE_6Fe_{11}Al_3$ and $RE_6Fe_{13}Ge$ Compounds", *J. Magn. Magn. Mater*., **117**, 25-231 (1992) (Crys. Structure, Experimental, Magn. Prop., Moessbauer, 14)

[1992Rae] Raevskaya, M.V., Tatarkina, A.L., Filippova, A.A., "Phase Equilibria in Systems Formed by Aluminum with Iron, Palladium and Cerium", *Russ. Metall.(Engl. Transl.)*, **6**, 161-165 (1992) (Crys. Structure, Equi. Diagram, Experimental, 18)

[1993Kat] Kattner, U.R., Burton, B.P., "Aluminum-Iron" in *Phase Diagrams of Binary Iron Alloys*, ASM, Metals Park, OH, 12-28 (1993) (Crys. Structure, Equi. Diagram, Review, Magn. Prop., Thermodyn., 99)

[1994Bur] Burkhardt, U., Grin, J., Ellner, M., Peters, K., "Structure Refinement of the Iron-Aluminium Phase with the Approximate Composition Fe_2Al_5", *Acta Crystallogr., Sect. B: Struct. Crystallogr. Crys. Chem.*, **B50**, 313-316 (1994) (Crys. Structure, Experimental, 9)

[1994Gri] Grin, J., Burkhardt, U., Ellner, M., Peters, K., "Refinement of the Fe_4Al_{13} Structure and its Relationship to Quasihomological Homotypical Structures", *Z. Kristallogr.*, **209**, 479-487 (1994) (Crys. Structure, Experimental, 39)

[1996Mis] Mishra, S.R., Long, G.J., Pringle, O.A., Hu, Z., Yelon, W.B., Middleton, D.P., Buschow, K.H.J., Grandjean, F., "A Magnetic Neutron Diffraction, and Mossbauer Spectral Study of the $Ce_2Fe_{17-x}Al_x$ Solid Solutions", *J. Appl. Phys.*, **79**(8), 5945 (1996) (Abstract, Crys. Structure, Experimental, 0)

[1996Sac] Saccone, A., Cardinale, A.M., Delfino, S., Ferro, R., "Phase Equilibria in the Rare Eearth Metals (R)-Rich Regions of the R-Al Systems (R=La, Ce, Pr, Nd)", *Z. Metallkd.*, **87**(2), 82-87 (1996) (Equi. Diagram, Cryst. Structure, Experimental, 18)

[1997Fer] Fernandez, G.E., Gomez-Berisso, M., Trovarelli, O., Sereni, J.G., "Comparative Study of the Ferro-Antiferromagnetic Transition in Ce(Fe, Co) and Ce(Fe, Al)$_2$", *J. Alloys Compd.*, **261**, 26-31 (1997) (Experimental, Magn. Prop., Thermal Conduct., Thermodyn., 41)

[1997Kog] Kogachi, M., Haraguchi, T., "Quenched-in Vacansies in B2-Structured Intermetallic Compound FeAl", *Mater. Sci. Eng. A*, **A230**, 124-131 (1997) (Crys. Structure, Experimental, 23)

[1997Spa] Spatz, P., Gross, K.J., Zuettel, A., Schlapbach, L., "Hydriding Properties of Ce(Mn,Al)$_2$ and Ce(Fe,Al)$_2$ Intermetallic Compounds", *J. Alloys Compd.*, **260**, 211-216 (1997) (Crys. Structure, Experimental, 10)

[1998Ali] Aliravci, C.A., Pekgueleryuez, M.O., "Calculation of Phase Diagrams for the Metastable Al-Fe Phases Forming in Direct-Chill (DC)-Cast Aluminium Alloy Ingots", *Calphad*, **22**, 147-155 (1998) (Calculation, Equi. Diagram, 20)

[1998Kuc] Kuchin, A.G., Ermolenko, A.S., Khrabrov, V.I., "Magnetic State of Pseudobinary Alloys $Lu_2Fe_{15.3}M_{1.7}$ and $Ce_2Fe_{15.3}M_{1.7}$ (M = Si and Al)", *Phys. Met. Metallogr. (Engl. Transl.)*, **86**(3), 276-280 (1998) (Crys. Structure, Experimental, 0)

[1998Thi] Thiede, V.M.T., Ebel, T., Jeitschko, W., "Ternary Aluminides LnT_2Al_{10}(Ln =Y, La-Nd, Sm, Cd-Lu and T=Fe,Ru,Os) with $YbFe_2Al_{10}$ Type Structure and Magnetic Properties of the Iron-Containing Series", *J. Mater. Chem.*, **8**(1), 125-130 (1998) (Crys. Structure, Experimental, Magn. Prop., 31)

[1998Sch] Schobinger-Papamantellos, P., Buschow, K.H.J., Ritter, C., "Magnetic Ordering and Phase Transitions of RFe_4Al_8 (R = La, Ce, Y, Lu) Compounds by Neutron Diffractioin", *J. Magn. Magn. Mater.*, **186**, 21-32 (1998) (Crys. Structure, Experimental, Magn. Prop., 13)

[1998Fas] Fass, M., Eliezer, D., Aghion, E., Froes, F.H., "Hardening and Phase Stability in Rapidly Solidified Al-Fe-Ce Alloys", *J. Mater. Sci*., **33**(3), 833-837 (1998) (Equi. Diagram, Experimental, Mechan. Prop., 22)

[1999Dub] Dubrovinskaia, N.A., Dubrovinsky, L.S., Karlsson, A., Saxena, S.K., Sundman, B., "Experimental Study of Thermal Expansion and Phase Transformations in Iron-Rich Fe-Al Alloys", *Calphad*, **23**(1), 69-84 (1999) (Equi. Diagram, Experimental, 14)

[2000Kon] Konishi, K., Kamimori, T., Tange, H., Deguchi, H., Kawae, T., Takeda, K., "Magnetic Properties of Heavy Fermion Compounds $Ce_2Fe_{17-x}Al_x$", *Physica B*, **284-288**, 1275-1276 (2000) (Experimental, Magn. Prop., 6)

[2000Kny] Knyazev, Yu.V., Kuchin, A.G., Kuz'min, Yu.I., "Optical Properties of Intermetallic Compounds Ce_2Fe_{17} and $Ce_2Fe_{15.3}M_{1.7}$ (M = Al, Si)", *Phys. Met. Metallogr.*, **89**(6), 558-562 (2000) (Crys. Structure, Experimental, Magn. Prop., Optical Prop., 16)

[2000Tam] Tamura, I., Mizushima, T., Isikawa, Y., Sakurai, J., "Moessbauer Effect and Magnetization Studies of $CeFe_2Al_8$ and $LaFe_2Al_8$", *J. Magn. Magn. Mater.*, **220**, 31-38 (2000) (Crys. Structure, Experimental, Moessbauer, 4)

[2000Sik] Sikora, W., Schobinger-Papamantellos, P., Buschow, K.H.J., "Symmetry Analysis of the Magnetic Ordering in RFe_4Al_8 (R=La, Ce, Y, Lu and Tb) Compounds (II)", *J. Magn. Magn. Mater.*, **213**, 143-156 (2000) (Calculation, Crys. Structure, Magn. Prop., 8)

[2000Cha] Chaboy, J., Piquer, C., Garcia, L.M., Bartolome, F., Wada, Maruyama, H., Kawamura, N., "X-Ray Absorption Spectroscopy Study of the Instability of Ferromagnetism in $CeFe_2$: Effects of Co and Al Substitutions", *J. Appl. Phys.*, **87**(9), 6809-6811 (2000) (Magn. Prop., 11)

[2000Hag] Hagmusa, I.H., Brueck, E., de Boer, F.R., Buschow, K.H.J., "A Specific-Heat Study of some RFe_4Al_8 Compounds (R = Ce, Pr, Nd, Dy, Ho, Tm)", *J. Alloys Compd.,* **298**, 77-81 (2000) (Crys. Structure, Experimental, Thermodyn., 16)

[2001Gac] Gaczynski, P., Vagizov, F.G., Suski, W., Kotur, B., Iwasieczko, W., Drulis, H., "Magnetic and Hyperfine Interaction in RFe_4Al_8 (R = Ce, Sc) Compounds", *J. Magn. Magn. Mater.*, **225**, 351-358 (2001) (Crys. Structure, Experimental, Magn. Prop., Moessbauer, 15)

[2001Ike] Ikeda, O., Ohnuma, I., Kainuma, R., Ishida, K., "Phase Equilibria and Stability of Ordered BCC Phases in the Fe-Rich Portion of the Fe-Al System", *Intermetallics*, **9**, 755-761 (2001) (Equi. Diagram, Experimental, Mechan. Prop., 18)

[2001Kny] Knyazev, Yu.V., Kuchin, A.G., Kuz'min, Yu.I., "Optical Conductivity and Magnetic Parameters of the Intermetallic Compounds $R_2Fe_{17-x}M_x$ (R = Y, Ce, Lu; M = Al, Si)", *J. Alloys Compd.*, **327**, 34-38 (2001) (Crys. Structure, Experimental, Magn. Prop., Optical Prop., 23)

[2001Kol] Kolenda, M., Koterlin, M.D., Hofmann, M., Penc, B., Szytula, A., Zygmunt, A., Zukrowski, J., "Low Temperature Neutron Diffraction Study of the $CeFe_2Al_8$ Compound", *J. Alloys Compd.,* **327**, 21-26 (2001) (Crys. Structure, Experimental, Magn. Prop., 10)

[2002Ram] Rama Rao, K.V.S., Ehrenberg, H., Markandeyulu, G., Varadaraju, U.V., Venkatesan, M., Suresh, K.G., Murthy, V.S., Schidt, P.C., Fuess, H., "On the Structural and Magnetic Properties of $R_2Fe_{(17-x)}(A,T)_x$ (R = Rare Earth; A = Al, Si, Ga; T = Transition Metal)

Compounds", *Phys. Status Solidi A*, **189**(2), 373-388 (2002) (Crys. Structure, Magn. Prop., Review, 51)

[2002Zha] Zhang, C., Wu, Y., Cai, X., Zhao, F., Zheng, S., Zhou, G., Wu, S., "Icosahedral Phase in Rapidly Solidified Al-Fe-Ce Alloy", *Mater. Sci. Eng. A*, **A323**, 226-231 (2002) (Equi. Diagram, Experimental, 23)

[2003Pis] Pisch, A., "Al-Fe (Aluminum-Iron)", MSIT Binary Evaluation Program, in *MSIT Workplace,* Effenberg, G. (Ed.), MSI, Materials Science International Services GmbH, Stuttgart; to be published, (2003) (Equi. Diagram, Crys. Structure, Assessment, 58)

Table 1: Crystallographic Data of Solid Phases

Phase / Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(βAl)	*hP*2 $P6_3/mmc$ Mg	*a* = 269.3 *c* = 439.8	at 25°C, 20.5 GPa [Mas2]
(αAl) < 660.452	*cF*4 $Fm\bar{3}m$ Cu	*a* = 404.96	at 25°C [Mas2]
(εFe)	*hP*2 $P6_3/mmc$ Mg	*a* = 246.8 *c* = 396.0	at 25°C, 13 GPa [Mas2]
(δFe) 1538-1394	*cI*2 $Im\bar{3}m$ W	*a* = 293.15	[Mas2]
(γFe) < 1394-912	*cF*4 $Fm\bar{3}m$ Cu	*a* = 364.67	at 915°C [V-C2, Mas2] dissolves up to 1.2 at.% Al
(αFe) < 912	*cI*2 $Im\bar{3}m$ W	*a* = 286.65 *a* = 286.64 to 289.59 *a* = 286.60 to 289.99 *a* = 286.60 to 290.12	at 25°C [Mas2] dissolves up to 45.0 at.% Al at 1310°C 0 - 18.8 at.% Al, HT [1958Tay] 0 - 19.0 at.% Al, HT [1961Lih] 0 - 18.7 at.% Al, 25°C [1999Dub]
(α'Ce)	*oC*4 *Cmcm* αU	*a* = 304.9 *b* = 599.8 *c* = 521.5	at 25°C, 5.4 GPa [Mas2]
(δCe) 798-726	*cI*2 $Im\bar{3}m$ W	*a* = 412	[Mas2]
(γCe) 726-61	*cF*4 $Fm\bar{3}m$ Cu	*a* = 516.10	[Mas2]
(βCe) 61-(-177)	*hP*4 $P6_3/mmc$ αLa	*a* = 368.10 *c* = 1185.7	at 25°C [Mas2]

Phase / Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(αCe) < -177	*cF*4 *Fm*$\bar{3}$*m* Cu	*a* = 485	[Mas2]
Fe_4Al_{13} < 1160	*mC*102 *C2/m* Fe_4Al_{13}	*a* = 1552.7 to 1548.7 *b* = 803.5 to 808.4 *c* = 1244.9 to 1248.8 β = 107.7 to 107.99° *a* = 1549.2 *b* = 807.8 *c* = 1247.1 β = 107.69°	74.16 - 76.70 at.% Al, [1986Gri] sometimes called $FeAl_3$ in the literature at 76.0 at.% Al, [1994Gri]
Fe_2Al_5 < 1169	*oC*24 *Cmcm* -	*a* = 765.59 *b* = 641.54 *c* = 421.84	at 71.5 at.% Al, [1994Bur]
$FeAl_2$ < 1156	*aP*18 *P1* FeAl2	*a* = 487.8 *b* = 646.1 *c* = 880.0 α = 91.75° β = 73.27° γ = 96.89°	at 66.9 at.% Al, [1993Kat]
ε 1232-1102	*cI*16*?* -	*a* = 598.0	at 61 at.% Al, [1993Kat]
FeAl < 1310	cP2 *Pm*$\bar{3}$*m* CsCl	*a* = 289.48 to 290.5 *a* = 289.53 to 290.9 *a* = 289.81 to 291.01 *a* = 289.76 to 190.78	34.5 - 47.5 at.% Al, [1961Lih] 36.2 - 50.0 at.% Al, [1958Tay] 39.7 - 50.9 at.% Al, [1997Kog] 500°C quenched in water room temperature
Fe_3Al < 547	*cF*16 *Fm*$\bar{3}$*m* BiF_3	*a* = 579.30 to 578.86 *a* = 579.30 to 578.92	~24-~37 at.% Al, [2001Ike] 23.1-35.0 at.% Al, [1958Tay] 24.7 - 31.7 at.% Al, [1961Lih]
Fe_2Al_9	*mP*22 $P2_1/c$ Co_2Al_9	*a* = 869 *b* = 635 *c* = 632 *β* = 93.4°	metastable 81.8 at.% Al [1993Kat]
$FeAl_6$	*oC*28 $Cmc2_1$ $FeAl_6$	*a* = 744.0 *b* = 646.3 *c* = 877.0 *a* = 744 *b* = 649 *c* = 879	metastable 85.7 at.% Al [1993Kat] [1998Ali]
$FeAl_{4+x}$	*t***	*a* = 884 *c* = 2160	(0 < *x* < 0.4) metastable [1998Ali]

Phase / Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
$Ce_2(Fe_{1-x}Al_x)_{17}$	*hR*57 $R\bar{3}m$		$0 \le x \le 0.67$
Ce_2Fe_{17}	Th_2Zn_{17}	$a = 851.2$ $c = 1245$	$x = 0$ [1969Zar]
		$a = 855.5$ $c = 1249.5$	$x = 0.1$ [1998Kuc]
		$a = 899.8$ $c = 1297$	$x = 0.67$ [1969Zar]
$Ce(Fe_{1-x}Al_x)_2$	*cF*24 $Fd\bar{3}m$	$a = 734 \pm 2$	$0 \le x \le 0.125$ [1985Fra] $x = 0.125$
$CeFe_e$	$MgCu_2$	$a = 730.4$	[V-C]
αCe_3Al_{11} < 1020	*oI*28 *Immm* $\alpha Al_{11}La_3$	$a = 439.5$ $b = 1302.$ $c = 1009$	[1988Gsc]
βCe_3Al_{11} 1235-1020	*tI*10 *I4/mmm* Al_4Ba	$a = 437.7$ $c = 1008$	[1988Gsc]
$CeAl_3$ < 1135	*hP*8 $P6_3/mmc$ Ni_3Sn	$a = 654.7$ $c = 461.0$	[1988Gsc]
$CeAl_2$ < 1480	*cF*24 $Fm\bar{3}m$ $MgCu_2$	$a = 806.1$	[1988Gsc]
CeAl < 845	*oC*16 *Cmc2* or *Cmcm* CeAl	$a = 926.9$ $b = 768.0$ $c = 576.1$	[1988Gsc]
βCe_3Al	*CP*4 $Pm\bar{3}m$ $AuCu_3$	$a = 498.9$	[1988Gsc]
αCe_3Al	*hP*8 $P6_3/mmc$ Ni_3Sn	$a = 704.2$ $c = 545.1$	[1988Gsc]
* τ_1, $CeFe_4Al_8$	*tI*26 *I4/mmm* ThMn12	$a = 886$ $c = 508$ $a = 880.5$ $c = 504.8$	[1961Gla] [1976Bus]
* τ_2, $CeFe_2Al_{10}$	*oC*52 *Cmcm* $YbFe_2Al_{10}$	$a = 900.02$ $b = 1022.2$ $c = 907.3$	[1998Thi]
* τ_3, $Ce_6Fe_{11}Al_3$		$a = 819.03$ $c = 2310.08$	[1992Hu]
* τ_4, $CeFe_2Al_8$	*oP44* $CeFe_2Al_8$	$a = 1251$ $b = 1448$ $c = 407$	[1974Yar]

Phase / Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
* τ_5, $CeFe_2Al_7$	?	?	[1969Zar] perhaps $CeFe_2Al_8$
* τ_6, $CeFe_{1-1.4}Al_{1-0.6}$	?	?	[1969Zar], not found and refused by [1976Bus]
* τ_7, CeFeAl	orthorh.	a = 1020 b = 1620 c = 420	metastable [1986Ang], sample containing 7 to 9 mass% Fe and 3 to 7 mass% Ce
* τ_8, $Ce_{7.4}Fe_{27.4}Al_{65.2}$	?	?	metastable [1987Yan]
* τ_9, $CeFe_5Al_{20}$	?	?	metastable [1988Aye] decagonal quasicrystal

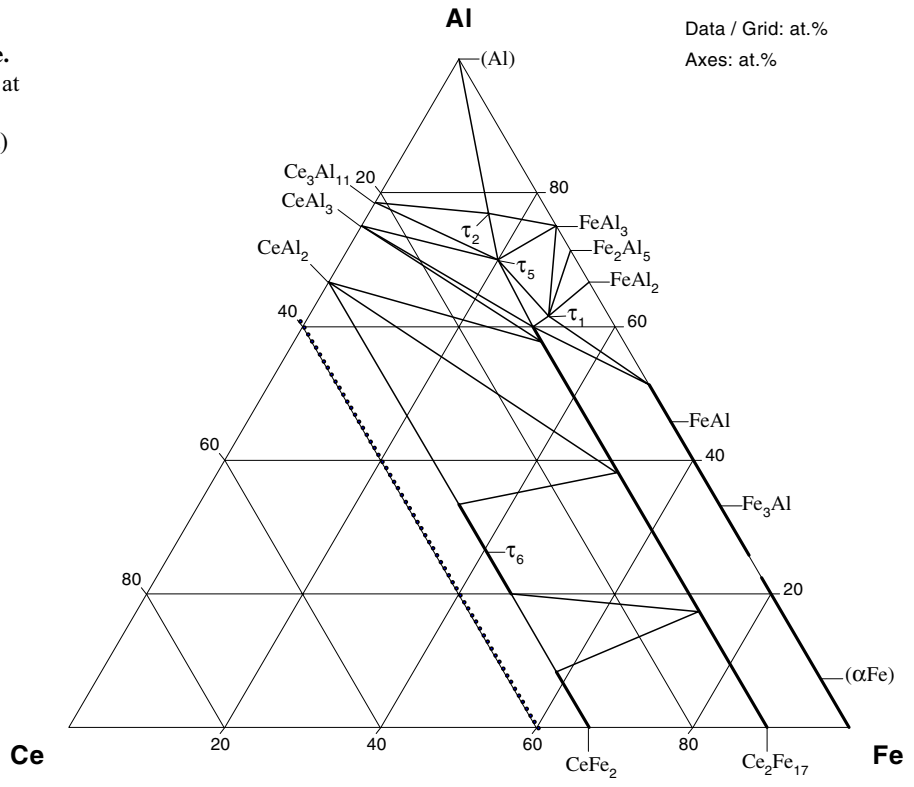

Fig. 1: Al-Ce-Fe. Isothermal section at 500°C, after [1969Zar] (revised)

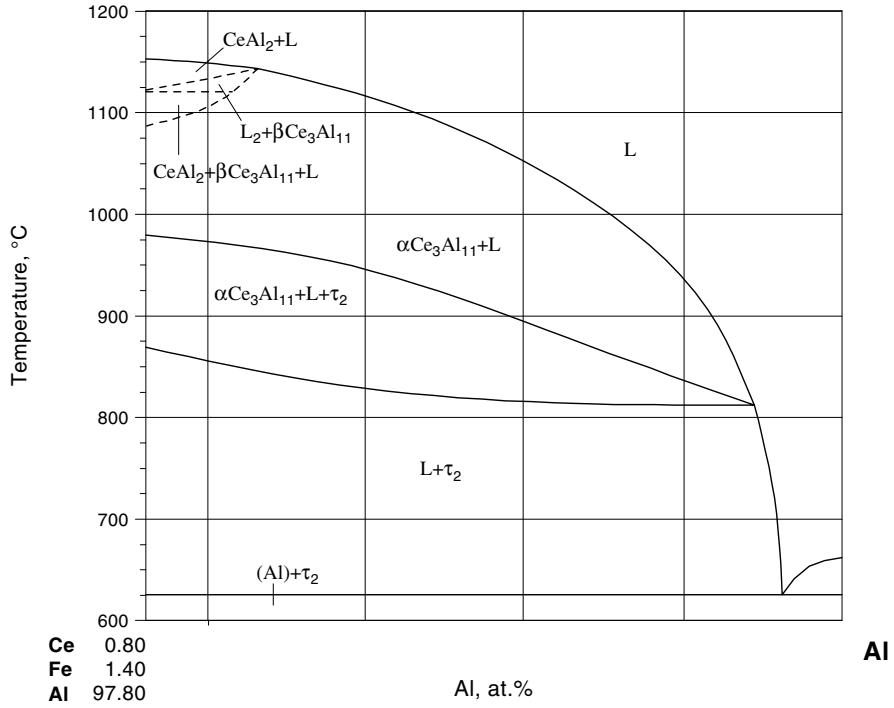

Fig. 2: Al-Ce-Fe. Isopleth along $CeFe_2Al_{10}$ - Al (partially), after [1988Sok]