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SELECTED PROPERTIES

OF IRON ALUMINIDES

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Abstract

Important properties of iron aluminides have been compiled in order to help engineers and scientists to be able to quickly assess this materials system. This compilation is by no means exhaustive, but it represents a reasonable first effort to summarize the properties of iron aluminides. Considerable care has been used in assembling the data into tables. However, no guarantee can be made that all the values compiled here are correct; and in case of doubt, or in order to obtain more detailed information, the original sources should always be consulted.

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Figure 1 - The B2 and D0₃ crystal structures.

Table I Lattice Parameter, a , at Room Temperature, in nm (see also Fig. 1)

Anneal	Al (at. %)							Ref.
	24.7	28.0	31.7	38.9	40	45	50	
Unspecified	0.28965	0.28965	0.28946	0.28960				1
Quenched from 1273 K					0.2895	0.2900	0.2905	2
Quenched from 773 K					0.2896	0.2903	0.2909	2

1. F. Lihl and H. Ebel, quoted in W. B. Pearson, A Handbook of Lattice Spacings and Structures of Metals and Alloys, Vol 2 (Pergamon, Oxford, 1967) p. 560.
2. Y. A. Chang, L. M. Pike, C. T. Liu, A. R. Bilbrey, and D. S. Stone, Intermetallics, 1 (1993), 107.

Table II Densities Derived from Compositions and Lattice Parameters

Composition (at. %)	Fe-25Al	Fe-40Al	Fe-45Al	Fe-50Al
Density (Mg/m ³)	6.65	6.06	5.82	5.59

60 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000

Table VI Thermal Expansion*

	Fe-28Al-5Cr-0.5Nb-0.2C (at. %) [†] (FA-129)			Fe-35.8Al-0.2Mo-0.05Zr-0.13C (at. %) ^{††} (FA-385)		
T (K)	Thermal Expansion (%), with respect to R. T.	Mean Coefficient of Thermal Expansion (ppm/K)	Instantaneous Coefficient of Thermal Expansion (ppm/K)	Thermal Expansion (%), with respect to R. T.	Mean Coefficient of Thermal Expansion (ppm/K)	Instantaneous Coefficient of Thermal Expansion (ppm/K)
373	0.1239	15.4	15.9	0.1499	18.3	18.7
473	0.2872	15.9	17.1	0.3414	19.0	20.2
573	0.4682	16.7	19.5	0.5520	19.6	21.4
673	0.6804	17.9	23.1	0.7719	20.3	22.3
773	0.9204	19.2	25.4	0.9896	20.6	23.2
873	1.1822	20.4	24.6	1.2222	21.1	24.1
973	1.4277	21.0	27.3	1.4703	21.6	26.3
1073	1.7037	21.8	28.7	1.7312	22.2	26.7
1173	2.0058	22.8	32.7	2.0190	22.9	30.5
1273	2.2924	23.4	24.5	2.3326	23.8	33.6
1373	2.5235	23.4	24.1	2.6856	24.8	37.9
1473	2.7700	23.5	24.7	3.1257	26.5	48.2

* W. D. Porter and P. J. Maziasz, Scr. Metall. Mater., 29 (1993), 1043.

(Note that the vertical axis of Fig. 1 in this reference is scaled incorrectly)

[†] Note that the DO₃ to B2 and the B2 to α (disordered Fe-Al solid solution) transitions occur at 816 and 1197 K, respectively

^{††} Note that the B2 to α (disordered Fe-Al solid solution) transition occurs at 1463 K

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Table VII Solid Solubility Limits of Some Ternary Elements in Iron Aluminides

Fe	Al (at. %)	Ternary Element (at.%)	Temperature (K)	Ref.
Bal	28	6 Mo	1123	1
Bal	40	6 Cr	as arc-melted	2
Bal	46	≥ 5 Cr	1525	3
Bal	46	≥ 5 Co	1525	3
Bal	25	16 Ti	1073	4
Bal	40	7.5 Ti	1073	4

1. C. G. McKamey and J. A. Horton, Metall. Trans. A, 20A (1989), 751.
2. P. R. Munroe and I. Baker, Scr. Metall. Mater., 24 (1990), 2273.
3. R. H. Titran, K. M. Vedula, and G. G. Anderson, High-Temperature Ordered Intermetallic Alloys, vol. 39, eds. C. C. Koch, C. T. Liu, and N. S. Stoloff (Pittsburg, PA: Materials Research Society, 1985), p. 309.
4. V. Raghavan, Phase Diagrams of Ternary Iron Alloys, Part I, Monograph on Alloy Phase Diagrams (ASM International, Metals Park, OH, 1987).

Table VIII Ceramics which are likely to be Thermodynamically Stable in FeAl at 1273 K*

Carbides	Borides	Oxides	Nitrides
HfC	HfB ₂	Al ₂ O ₃	HfN
TiC	ScB ₂	BeO	
ZrC	TiB ₂	La ₂ O ₃	
	ZrB ₂	Sc ₂ O ₃	
		Y ₂ O ₃	

* A. K. Misra, Metall. Trans. A, 21A (1990), 441.

Table IX Slip Systems in Fe-Al

Alloy (at. %)	Temperature (K)	Slip System	Ref.
Fe-25Al	295	<111>{110}	1
Fe-47Al	295	<111>{110}	2
	>700 K	<001>{100}	2

1. M. G. Mendiratta, S. K. Ehlers, D. K. Chatterjee, and H. A. Lipsitt, Metall. Trans., 18A (1987), 283.
2. Y. Umakoshi and M. Yamaguchi, Philos. Mag. A, 41 (1980), 573.

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Alloy (at. %)	Crystal Structure	$R_{NN}^{\dagger}$ (nm)	$R_{NNN}^{\dagger\dagger}$ (nm)	E_{NN} (mJ/m ²)	E_{NNN} (mJ/m ²)	Ref.
Fe-26.9Al	D0 ₃	10	23	69	71	1
Fe-26.9Al	B2	14		28		1
Fe-28Al	D0 ₃	7	37	76	46	2
Fe-28.3Al	D0 ₃	7	25	78	63	1
Fe-28.3Al	B2	9		44		1
Fe-31.1Al	B2	7		65		1
Fe-33.8Al	B2	5		95		1
Fe-39Al	B2	4-7 ^{†††}				3
Fe-28Al-4Cr	D0 ₃	15-18	60	29-35	28	2
Fe-28Al-4Cr	D0 ₃	6-16	28-34	80-90	60	4

[†] R_{NN} is the spacing of the leading or trailing dislocation pairs in the D0₃-structure, or the spacing between pairs of partial dislocations in the B2 structure, respectively

^{††} R_{NNN} is the spacing between the centers of the leading and trailing pair of a four-fold dislocation in the $D0_3$ structure

††† Dislocation orientations unspecified

1. R. C. Crawford and I. L. F. Ray, Philos. Mag., 35 (1977), 549.
2. C. G. McKamey, J. A. Horton, and C. T. Liu, J. Mater. Res., 4 (1989), 1156.
3. M. A. Crimp and K. Vedula, Philos. Mag. A, 63 (1991), 559.
4. D. G. Morris, M. M Dadra, and M. A. Morris, Acta Metall. Mater., 41 (1993) 97.

Table XI Elastic Properties at Room Temperature (GPa)

Composition (at. %)	Composition (wt.%)	C ₁₁	C ₁₂	C ₄₄	E	Ref.
Fe-25 Al	Fe-13.87Al	171	131	132		1
Fe-28Al	Fe-15.82Al	166	123	131		1
Fe-34Al	Fe-19.93Al	172	114	130		1
Fe-40Al	Fe-24.36Al	181	114	127		1
Fe-31Al	Fe-17.83Al				142	2
Fe-35Al	Fe-20.64Al				165	2
Fe-36Al	Fe-21.37Al				180	2
Fe-38Al	Fe-22.85Al				172	2
Fe-39Al	Fe-23.60Al				167	2
Fe-47Al	Fe-29.99Al				164	2
Fe-50Al	Fe-32.58Al				163	2

1. H. J. Leamy, E. D. Gibson, and F. X. Kayser, Acta Metall., 15 (1967), 1827.
2. T. Gödecke and W. Köster, Z. Metallkde., 77 (1986), 408.

**Table XII Yield Strength, Ultimate Tensile Strength, and Ductility
of Iron Aluminides at Room Temperature in Laboratory Air[†]**

Composition (at. %)	Processing	Yield Stress (MPa)	Ultimate Tensile Stress (MPa)	Fracture Strain (%)	Ref.
Fe-27.5Al-1.8Cr	Elemental powders, reaction Sintering, HIP 1373 K/207 MPa	884	1101	5	1
Fe-27.9Al-4.6Cr	Elemental powders, reaction sintering, HIP, final anneal 2 h/1023 K/oil quench	857	1095	7	1
Fe-27.9Al-4.6Cr	Extrusion of prealloyed powder, final anneal 2 h/1033 K/oil quench	358	726	11.8	1
Fe-40Al-0.02Zr (at. %)	Vacuum induction melting into chilled copper mold, as-cast			1.1	2
Fe-28Al-5Cr-0.1Zr-0.04B	Hot forging and hot rolling of arc-melted ingot, final anneal 1h/973 K/oil quench. Elongated grains	524	1038	19	3
Fe-28Al	Casting and hot-rolling, final anneal 7 d/773 K	279	514	3.7	4
Fe-28Al	thermomechanical treatment	350	890	12.3	5
Fe-28Al-2Cr	Casting and hot-rolling, final anneal 7 d/773 K	247	639	9.4	4
Fe-28Al-5Cr	thermomechanical treatment	345	777	16.8	5
Fe-28Al-6Cr	Casting and hot-rolling, final anneal 7 d/773 K	232	535	8.4	4
Fe-28Al-5CrZrMoNbB	thermomechanical treatment	530	950	14.1	
Fe-35.8Al	Recrystallization and 1-2 h at 973 K	334	621	7.6	6
Fe-35.8Al-0.2Mo-0.05Zr- 0.24B	Recrystallization and 1-2 h at 973 K	400	836	11.8	6

[†] Note that strength and ductility are often strongly affected by processing schedule and cooling rate

1. B. H. Rabin and R. N. Wright, Metall. Trans. A, 23A (1992), 35.
2. K.-M. Chang, Met. Trans. A, 21A (1990), 3027.
3. P. G. Sanders, V. K. Sikka, C. R. Howell, and R. H. Baldwin, Scr. Metall. Mater., 25 (1991), 2365.
4. C. G. McKamey, J. A. Horton, and C. T. Liu, Scripta Metall., 22 (1988), 1679.
5. Z. Q. Sun, Y. D. Huang, W. Y. Yang, and G. L. Chen, in High-Temperature Ordered Intermetallic Alloys V, vol. 288, eds. I. Baker, R. Darolia, J. D. Whittenberger, and M. H. Yoo (Pittsburg, PA: Materials Research Society, 1993), p. 885.
6. P. J. Maziasz, G. M. Goodwin, C. T. Liu, and S. A. David, Scr. Metall. Mater., 27 (1992), 1835.

Table XIII Critical Resolved Shear Stresses

Composition (at. %)	Anneal	Test Temperature (K)	CRSS (MPa)	Ref.
Fe-25Al	>3.6 ks/630 K	630	105-195	1
Fe-39Al	Slow cool from 1273 K	295	97±13	2
Fe-39Al	Oil quench from 1273 K	295	304±16	2
Fe-47Al	24 h/1123 K/slow cool	470	375	3
Fe-49Al	Slow cool from 1273 K	295	202±17	2
Fe-49Al	Oil quench from 1273 K	295	318±16	2

1. S. Hanada, S. Watanabe, T. Sato, and O. Izumi, Scr. Metall., 15 (1981), 1345.
2. M. A. Crimp and K. Vedula, Philos. Mag. A, 63 (1991), 559.
3. Y. Umakoshi and M. Yamaguchi, Philos. Mag. A, 41 (1980) 573.

Table XIV Work Hardening Rates of Iron Aluminides at Room Temperature and a Strain of 1%

Alloy (at. %)	Yield Strength (MPa)	Work Hardening Rate (GPa)	Ref.
Fe-28Al	360	6	1
	600	1	1
Fe-28Al-4Cr	225	3.7	1
Fe-31Al	560	6.9	2

1. D. G. Morris, M. M. Dadras, and M. A. Morris, Acta Metall. Mater., 41 (1993), 97.
2. M. G. Mendiratta, S. K. Ehlers, D. K. Chatterjee, and H. A. Lipsitt, Metall. Trans. A, 18A (1987), 283.

**Table XV Effect of different Environments on Tensile Ductility (%)
of Iron Aluminides at Room Temperature**

Composition (at. %)	Final Treatment	H ₂ O Vapor	Lab Air	Ar+4% H ₂	Silicone Oil Coating, in Air	Vacuum ($\approx 1 \times 10^{-4}$ Pa)	Oxygen	Ref.
Fe-24.6Al	Assorted		0.7-6.4				3.2-9.3	1
Fe-28Al	5 d/773 K	2.1	3.7			12.4	11.7 [†]	2
Fe-28Al	2 h/973 K	2.1	4.1	8.4 [†]		12.8	12.0 [†]	2
Fe-33Al	1 h/873 K		2.9				11.2	1
Fe-36.5Al	2 h/973 K	2.4	2.2	6.1 ^{†††}	5.6	5.4	11.3 ^{††}	3
Fe-36.5Al	2 h/973 K						17.6 [#]	4
Fe-40Al	2 h/973 K		1.2				3.2 [#]	4
Fe-40Al-0.1B	2 h/973 K		4.3				16.8 [#]	4

[†]67 kPa

^{††}67 Pa

^{†††}110 Pa

[#] 6.7×10^{-4} Pa

1. R. J. Lynch, K. A. Gee, and L. A. Heldt, Scr. Metall. Mater., 30 (1994), 945.
2. C. T. Liu, C. G. McKamey, and E. H. Lee, Scr. Metall. Mater., 24 (1990), 385.
3. C. T. Liu, E. H. Lee, and C. G. McKamey, Scr. Metall., 23 (1989), 875.
4. C. T. Liu and E. P. George, Scr. Metall. Mater., 24 (1990), 1285.

**Table XVI Tensile Properties of Fe-28Al-5Cr-0.5Nb-0.2C (FA-129)
at Different Temperatures***

T (°C)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation to Fracture (%)
20	412	824	14
93	378	954	15
204	357	1016	30
316	371	892	28
427	391	783	26
538	371	570	33
593	343	467	42
649	295	343	58
704	220	240	80
760	124	137	108

- * V. K. Sikka, data package on Fe₃Al- and Fe-Al-based alloys developed at ORNL, Oak Ridge National Laboratory, January 20, 1993.

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Table XIX Fracture Toughness of Iron Aluminides

Alloys (at. %) (polycrystalline unless noted otherwise)	K_{Ic} or K_{Q} (MPa m ^{1/2})	Heat Treatment	Test Method	Average Crack Velocity ($\mu\text{m/s}$)	Ref.
Fe-40Al, Single Crystal	33-56	as-solidified	Single-edge notch, 4-point bend test		1
Fe-48Al, Directionally solidified	12	as-solidified	"		1
Fe-40Al	≈ 40	1273 K/fast cool in vacuum	Chevron-notch 3-point bend test	300	2
Fe-40Al-0.1B	≈ 50	1273 K/fast cool in vacuum	"	200	2
Fe-45Al	≈ 12	1273 K/fast cool in vacuum	"	700	2
Fe-40Al	11-16	5 d/673 K	Fatigue pre-crack	"slow"	3
Fe-45Al	25-27	5 d/673 K	Fatigue pre-crack	"fast"	3

1. K.-M. Chang, R. Darolia, and H. A. Lipsitt, Acta Metall. Mater., 40 (1992), 2727.
2. J. H. Schneibel, M. G. Jenkins, and P. J. Maziasz, High-Temperature Ordered Intermetallic Alloys V, vol. 288, eds. I. Baker, R. Darolia, J. D. Whittenberger, and M. H. Yoo (Pittsburgh, PA: Materials Research Society, 1993), 549.
3. O. Klein, P. Nagpal, and I. Baker, *ibid.*, p. 935.

**Table XX Creep Data for Fe₃Al-Based Iron Aluminides
at an Applied Stress of 138 MPa***

Composition (at. %)	Temperature (K)	Creep Life (h)	Minimum Creep Rate (s ⁻¹)	Elongation to Fracture (%)	Ref.
Fe-28Al	823	87	6.1×10^{-7}	30	1
"	873	5.8	1.3×10^{-5}	34	1
"	923	0.6	8.5×10^{-5}	37	1
Fe-28Al-2Mo	873	835	1.1×10^{-7}	40	1
"	923	50	1.3×10^{-6}	44	1
Fe-28Al-1Nb	873	>1975	1.9×10^{-9}	>1	1
"	923	304	1.4×10^{-8}	37	1
Fe-35.8Al	866	46.4	6.4×10^{-7}	28	2
Fe-35.8Al-0.2Mo- 0.05Zr-0.24B	866	932	8.3×10^{-8}	74	2

1. C. G. McKamey, P. J. Maziasz, and J. W. Jones, J. Mater. Res., 7 (1992), 2089.
2. P. J. Maziasz, G. M. Goodwin, C. T. Liu, and S. A. David, Scr. Metall. Mater., 27 (1992), 1835.

Table XXI 1000 h Rupture Strengths for Fe₃Al-Based Iron Aluminides*

Composition (at. %)	823 K	873 K	923 K
Fe-28.1Al-2Cr-0.04B	98	55	31
Fe-28Al-5Cr-0.08Zr-0.04B	117	65	36
Fe-28.1Al-5Cr-0.5Nb-0.2C	149	77	40

* V. K. Sikka and R. H. Baldwin, SAMPE Quart., 24, No 1 (1992), 2.

Table XXII Stresses Needed to Produce a Secondary Creep Rate of 10^{-7} s^{-1} in FeAl-Based Iron Aluminides

Composition (at. %)	1023 K	1100 K	1173 K	1200 K	Ref.
Fe-48.7Al		12 MPa		7 MPa	1
Fe-40Al				5 MPa	1
Fe-40Al-2 vol. % Y ₂ O ₃				22 MPa	2
Fe-10Ni-50Al	100 MPa		15		3

1. J. D. Whittenberger, Mater. Sci. Eng., 77 (1986), 103.
2. J. H. Schneibel, P. Grahle, and J. Rösler, Mater. Sci. Eng., A153 (1992), 684.
3. I. Jung, M. Rudy, and G. Sauthoff, in High-Temperature Ordered Intermetallic Alloys II, vol. 81, eds. N. S. Stoloff, C. C. Koch, C. T. Liu, and O. Izumi (Pittsburgh, PA: Materials Research Society, 1987), 263.

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3^a After cooling from exposure temperature

[†] P. F. Tortorelli, unpublished Research, Oak Ridge National Laboratory

Table XXIV Weight Gains of Fe₃Al Exposed to N₂-1% O₂-0.5% SO₂*

Temperature (°C)	Salt Deposit ^a	Weight Gain After 96 h (mg/cm ²)
600	none	<0.1
700	none	0.6
800	none	0.4
600	Na ₂ SO ₄ -10wt% NaCl	4.6
700	Na ₂ SO ₄ -10wt% NaCl	1.9
800	Na ₂ SO ₄ -10wt% NaCl	2.3

* P. F. Tortorelli and J. H. DeVan in Section 3 from Chapter 3, "Oxidation and Other Corrosion Phenomena At Intermediate Temperatures (300 - 800°C)," in Corrosion and Oxidation of Intermetallic Alloys, G. Welsch and P. D. Desai (editors), DoD Metals Information Analysis Center, to be published in 1994.

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Acknowledgments

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