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Thermodynamic Analysis of Compatibility of Several Reinforcement Materials With FeAl Alloys

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THERMODYNAMIC ANALYSIS OF COMPATIBILITY OF SEVERAL REINFORCEMENT MATERIALS WITH FeAl ALLOYS

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SUMMARY

Chemical compatibility of several reinforcement materials with FeAl alloys within the concentration range 40 to 50 at % Al have been analyzed from thermodynamic considerations at 1173 and 1273 K. The reinforcement materials considered in this study include carbides, borides, oxides, nitrides, and silicides. Although several chemically compatible reinforcement materials have been identified in this study, the coefficients of thermal expansion for none of these materials match closely with that of FeAl alloys and this might pose serious problems in the design of composite systems based on FeAl alloys.

INTRODUCTION

Fiber-reinforced intermetallic matrix composites are of considerable interest as high temperature engine materials. The key factors in the selection of a suitable fiber-reinforcement material are (1) chemical compatibility between the fiber and the matrix, and (2) close match in coefficient of thermal expansion (CTE) between the fiber and the matrix. In an earlier report (ref. 1) the criteria for chemical compatibility between the reinforcement material and the matrices were defined and chemical compatibility of several reinforcement materials with NiAl alloys were examined from thermodynamic consideration. In this report we examine the chemical compatibility of several reinforcement materials with FeAl alloys from thermodynamic considerations. Since FeAl-based systems would be used in the lower temperature range, i.e., between 1073 and 1373 K, all the thermodynamic calculations were performed at 1173 and 1273 K.

MATRICES AND REINFORCEMENT MATERIALS

The matrices considered in this study are ordered FeAl alloys with concentrations ranging from 40 to 50 at % Al. The reinforcement materials include carbides, borides, oxides, nitrides, silicides, and Be-rich intermetallic compounds. A list of reinforcement materials considered in this study is given in table I.

CALCULATION PROCEDURES

Details of the calculation procedures have been described in the previous report (ref. 1) and need not be repeated here. However, a brief summary of the calculation procedures will be given in this section. A summary of the

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sequence of steps required to determine the chemical compatibility of an intermetallic matrix consisting of elements A and B with a reinforcement material consisting of elements C and D is given below.

(1) Obtain the activities of A and B in the intermetallic matrix.

(2) Identify the product compounds in the binary systems A-C, B-C, A-D, B-D that would be stable in the intermetallic matrix.

(3) Examine the feasibility of reactions involving reduction of the reinforcement material by an element of the intermetallic matrix. These reduction reactions can be expressed as:

$$x\underline{A} + yCD = A_xC_y + yD \tag{1}$$

$$p\underline{A} + qCD = A_pD_q + qC \tag{2}$$

$$i\underline{B} + jCD = B_iC_j + jD \tag{3}$$

$$m\underline{B} + nCD = B_mD_n + nC \tag{4}$$

If the activities of A or B in the alloy are greater than certain minimum values as dictated by the equilibria for the above reactions, then reductions reactions are feasible. The reinforcement material would be considered incompatible with the matrix if any of the reactions (1) to (4) are feasible.

(4) If none of the reactions (1) to (4) are feasible, then consider simultaneous formation of two product compounds via reactions:

$$(qX + pY)\underline{A} + (qy)CD = (q)A_xC_y + (y)A_pD_q \tag{5}$$

$$(nx)\underline{A} + (ym)\underline{B} + (ny)CD = (n)A_xC_y + (y)B_mD_n \tag{6}$$

$$(in + jm)\underline{B} + (jn)CD = (n)B_iC_j + (j)B_mD_n \tag{7}$$

$$(jp)\underline{A} + (iq)\underline{B} + (jq)CD = (j)A_pD_q + (q)B_iC_j \tag{8}$$

For reaction (5) to occur, the activity of A in the alloy must be greater than the equilibrium activity of A for this reaction. Similarly, for reaction (7) to occur, the activity of B in the alloy must be greater than the equilibrium activity of B for this reaction. Reactions (6) and (8) would take place if the product of the activities of A and B in the alloy are greater than the equilibrium activity product for these reactions. If any of the reactions (5) to (8) are feasible, then the reinforcement material can be considered to be incompatible with the matrix.

(5) If none of the reactions (1) to (8) are feasible, then the primary mode of reaction would be dissolution of the elements of the reinforcement material in the matrix and we need to calculate the minimum possible values for the activity of C and D in the matrix, which are designated as $(a_C)_{min}$ and $(a_D)_{min}$. Activity values greater than 10^{-3} are considered to be high and activity values less than 10^{-3} are considered to be low. If $(a_C)_{min}$ and $(a_D)_{min}$ are calculated to be less than 10^{-3}, the reinforcement material is considered to be compatible with the matrix, otherwise not.

ACTIVITY OF Fe AND Al IN FeAl ALLOYS

Radcliffe et al. (ref. 2) have measured the activity of Al in Fe-Al alloys in the temperature range 1148 to 1273 K by e.m.f. measurements using a molten chloride electrolyte. Iron activities in the alloys were obtained by Gibbs-Duhem integration of the Al activity data. The activity data at 1173 and 1273 K for alloys within the concentration range 40 to 50 at % Al are given in tables II and III. The change in activity values between 40 and 50 at % Al is observed to be relatively small. This is in contrast to that of NiAl alloys for which the activities of Ni and Al change by two orders of magnitude within the concentration range 48 to 50 at % Al (ref. 1).

THERMODYNAMIC DATA FOR COMPOUNDS

Appendix A gives the Gibbs free energy of formation (ΔG_f^o) of different compounds at 1173 and 1273 K. Unless otherwise stated in the appendix, most of the thermodynamic data were taken either from JANAF Thermochemical Tables (ref. 3) or from the compilations by Barin and Knacke (ref. 4). The Gibbs free energies of formation data for many intermetallic compounds are not available and for such compounds, if enthalpy of formation at 298 K (ΔH_{298}^o) are available, ΔG_f^o is assumed to be the same as ΔH_{298}^o. If the Gibbs free energy of formation data are available only at one temperature, then the same value is assumed at other temperatures. The Gibbs energies of formation data given in appendix A for compounds containing elements with low melting points like Al, Ca, La, and Mg are derived with respect to solid as the standard reference state for these elements.

POSSIBLE STABLE PRODUCT COMPOUNDS IN THE MATRIX

The stable binary product compounds that can possibly be formed as a result of interaction of the intermetallic matrix with the elements of the reinforcement materials considered in this study are given in appendix B.

RESULTS AND DISCUSSION

A summary of the results of the thermodynamic calculations are given in tables IV to VIII which indicate the principal mode of reaction between FeAl alloys and the reinforcement materials and any comments concerning the compatibility of a given reinforcement material. For situations in which the principal mode of reaction between the reinforcement material and the intermetallic matrix is dissolution of the elements of the reinforcement material in the alloy, tables IV to VIII would indicate whether the minimum values for the activities of these elements in the matrix are high or low, i.e., whether the activities are greater than 10^{-3} or not. The exact values for these activities as a function of alloy composition and temperature are given in appendix C. Since Fe and Al activities in the alloy change only by a small margin between 40 and 50 at % Al, $(a_C)_{min}$ and $(a_D)_{min}$ values for only two alloy compositions, i.e, 40 and 50 at % Al, will be given in appendix C.

There are several carbides which are likely to be compatible with FeAl alloys and a list of these in order of increasing values for $(a_{Me})_{min}$. (Me stands for metallic element of the carbide) is given in table IX. Among all the carbides Al_4C_3, HfC, ZrC, and TiC appear to the most compatible ones. A list of compatible borides in order of increasing $(a_{Me})_{min}$ values is given in table X. The most compatible borides for all FeAl alloys within the concentration range 40 to 50 at % Al are HfB2, ScB2, ZrB2, and TiB2. Compatible oxides include Al_2O_3, Y_2O_3, Sc_2O_3, Gd_2O_3, La_2O_3, and BeO and table XI lists these oxides in order of increasing values for $(a_{Me})_{min}$. Among nitrides, HfN and AlN appear to be the only ones which would be compatible with FeAl alloys at both the temperatures, i.e., 1173 and 1273 K. TiN is compatible at 1173 K, but not at 1273 K. Two silicides, Ti_5Si_3 and TiSi, appear to be compatible with FeAl alloys at both the temperatures.

Besides chemical compatibility between the matrix and the reinforcement materials, the coefficient of thermal expansion (CTE) of the reinforcement material should match closely with that of the matrix. The CTE for FeAl alloys at 1200 K are in the range of 21 to 22×10^{-6} K^{-1} (ref. 5). Thermal expansion coefficients for the compatible reinforcement materials at 1200 K are given in table XII in order of decreasing CTE values. All the CTE data were taken from the handbook on thermal expansion of materials (refs. 5 and 6). As can be seen from table XII, the CTE for all the compatible materials are substantially lower than that of FeAl alloys and it will be an extremely difficult task to find a suitable reinforcement whose CTE would match closely with that of FeAl alloys. Therefore proper methods like graded coatings or addition of a compliant ductile layer between the fiber and the matrix must be developed in order to alleviate the problem of CTE mismatch between the fibers and the FeAl matrix.

CONCLUDING REMARKS

Chemical compatibility of several potential reinforcement materials with FeAl alloys with concentrations ranging from 40 to 50 at % Al have been analyzed from thermodynamic considerations. The reinforcement materials considered in this study include carbides, borides, nitrides, oxides, and silicides. The reinforcement materials that appear to be promising on the basis of compatibility criteria alone include Al_4C_3, HfC, ZrC, TiC, HfB_2, ScB_2, ZrB_2, TiB_2, Al_2O_3, Y_2O_3, Sc_2O_3, Gd_2O_3, La_2O_3, BeO, Ti_5Si_3, and TiSi. However, none of these have coefficients of thermal expansion close to that of FeAl alloys. The thermal expansion coefficient of Be-rich intermetallic compounds like Nb_2Be_{17}, Ti_2Be_{17}, and $ZrBe_{13}$ match closely with that of FeAl alloys. However, due to the lack of thermodynamic data for Fe-Be compounds, these beryllides were not considered in this study. However, based on the calculations for the compatibility of NiAl alloys with Be-rich intermetallic compounds (ref. 1), it is likely that FeAl alloys would not be chemically compatible with Be-rich intermetallic compounds. There might be other intermetallic compounds whose coefficients of thermal expansion would match with those of FeAl alloys and work is in progress to identify such compounds and examine the compatibility of these with FeAl alloys.

The reinforcement materials identified in this study are on the basis of thermodynamic considerations only; kinetic factors were not considered in this study. It is possible that there might be several other reinforcement materials for which thermodynamics show that they would react with the matrix, but the kinetics of the reactions might be very slow. In such cases, the reinforcement materials would be acceptable if the reaction products do not adversely affect the performance of the composite. Indeed, limited reaction between the fiber and the matrix might be desirable for creating a strong bond between the two.

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TABLE I. - REINFORCEMENT MATERIALS CONSIDERED IN THIS STUDY

Carbides	Borides	Oxides	Nitrides	Silicides
B_4C	AlB_{12}	Al_2O_3	AlN	Cr_3Si
HfC	CrB_2	BeO	BN	Cr_5Si_3
Mo_2C	HfB_2	CaO	HfN	Mo_3Si
Nb_2C	LaB_6	CeO_2	LaN	Mo_5Si_3
NbC	NbB_2	Cr_2O_3	Si_3N_4	$MoSi_2$
SiC	ScB_2	Gd_2O_3	TaN	Nb_5Si_3
TaC	TaB_2	HfO_2	TiN	$NbSi_2$
Ta_2C	TiB_2	La_2O_3	ZrN	Ta_2Si
TiC	TiB	MgO		Ta_5Si_3
V_2C	VB	Sc_2O_3		$TaSi_2$
VC	VB_2	SiO_2		Ti_5Si_3
W_2C	V_3B_2	TiO		TiSi
WC	V_2B_3	TiO_2		V_3Si
ZrC	ZrB_2	Y_2O_3		V_5Si_3
		ZrO_2		VSi_2
		Ca_2SiO_4		W_5Si_3
		$CaZrO_3$		WSi_2
		$Y_2O_3.2ZrO_2$		Zr_2Si
				Zr_5Si_3
				ZrSi

TABLE II. - ACTIVITIES OF Fe AND Al IN FeAl ALLOYS AT 1173 K
[Activity of Al is with respect to solid Al.]

Alloy composition, at % Al	a_{Fe}	a_{Al}
40	0.217	0.022
42	0.202	0.024
44	0.190	0.026
46	0.181	0.028
48	0.174	0.029
50	0.170	0.03

TABLE III. - ACTIVITIES OF Fe AND Al IN FeAl ALLOYS AT 1273 K
[Activity of Al is with respect to solid Al.]

Alloy composition, at % Al	a_{Fe}	a_{Al}
40	0.233	0.035
42	0.217	0.039
44	0.204	0.042
46	0.194	0.045
48	0.187	0.047
50	0.181	0.045

TABLE IV. - COMPATIBILITY OF FeAl ALLOYS WITH CARBIDES

Reinforcement material	Temperature, K	Alloy composition, at % Al	Mode of reaction	Comments on compatibility
C	1173 and 1273	40 - 50	Al_4C_3 formation	Not compatible
B_4C	1173 and 1273	40 - 50	Formation of FeB and free carbon	Not compatible
HfC	1173 and 1273	40 - 50	Dissolution of Hf and C in the matrix; low values for $(a_{Hf})_{min}$ and $(a_C)_{min}$	Compatible
Mo_2C	1173 and 1273	40 - 50	Dissolution of Mo and C in the matrix; high values for both $(a_{Mo})_{min}$ and $(a_C)_{min}$	Compatibility depends on solubility of Mo and C in the matrix
Nb_2C	1173 and 1273	40	Formation of Fe_2Nb and Al_4C_3	Not compatible
		42 - 50	Formation of $NbAl_3$ and Al_4C_3	Not compatible
NbC	1173 and 1273	40 - 50	Dissolution of Nb and C in the matrix; low values for $(a_{Nb})_{min}$; high values for $(a_C)_{min}$	Compatibility depends on solubility of C in the matrix
SiC	1173 and 1273	40 - 50	Formation of FeSi and Al_4C_3	Not compatible
TaC	1173 and 1273	40 - 50	Dissolution of Ta and C in the matrix; low values for both $(a_{Ta})_{min}$ and $(a_C)_{min}$	Compatible
Ta_2C	1173 and 1273	40 - 50	Dissolution of Ta and C in the matrix; low values for both $(a_{Ta})_{min}$ and $(a_C)_{min}$	Compatible
TiC	1173 and 1273	40 - 50	Dissolution of Ti and C in the matrix; low values for both $(a_{Ti})_{min}$ and $(a_C)_{min}$	Compatible
V_2C	1173 and 1273	40 - 50	Dissolution of V and C in the matrix; low values for both $(a_V)_{min}$ and $(a_C)_{min}$	Compatible
VC	1173 and 1273	40 - 50	Dissolution of V and C in the matrix; low values for both $(a_V)_{min}$ and $(a_C)_{min}$	Compatible
W_2C	1173 and 1273	40 - 50	Dissolution of W and C in the matrix; low values for $(a_C)_{min}$; high values for $(a_W)_{min}$	Compatibility depends on solubility of W in the matrix
WC	1173 and 1273	40 - 50	Dissolution of W and C in the matrix; high values for both $(a_C)_{min}$ and $(a_W)_{min}$	Compatibility depends on solubility of W and C in the matrix
ZrC	1173 and 1273	40 - 50	Dissolution of Zr and C in the matrix; low values for both $(a_{Zr})_{min}$ and $(a_C)_{min}$	Compatible

TABLE V. - COMPATIBILITY OF FeAl ALLOYS WITH BORIDES

Reinforcement material	Temperature, K	Alloy composition, at % Al	Mode of reaction	Comments on compatibility
AlB_{12}	1173 and 1273	40 - 50	Formation of FeB	Not compatible
CrB_2	1173 and 1273	40 - 50	Dissolution of Cr and B in the matrix; high values for both $(a_{Cr})_{min}$ and $(a_B)_{min}$	Not compatible
HfB_2	1173 and 1273	40 - 50	Dissolution of Hf and B in the matrix; low values for both $(a_{Hf})_{min}$ and $(a_B)_{min}$	Compatible
LaB_6	1173 and 1273	40 - 50	Dissolution of La and B in the matrix; low values for $(a_{La})_{min}$; high values for $(a_B)_{min}$	Compatibility depends on solubility of B in the matrix
NbB_2	1173 and 1273	40 - 41	Formation of FeB and Fe_2Nb	Not compatible
		42 - 50	Formation of FeB and $NbAl_3$	Not compatible
ScB_2	1173 and 1273	40 - 50	Dissolution of Sc and B in the matrix; low values for both $(a_{Sc})_{min}$ and $(a_B)_{min}$	Compatible
TaB_2	1173 and 1273	40 - 50	Dissolution of Ta and B in the matrix; low values for both $(a_{Ta})_{min}$ and $(a_B)_{min}$	Compatible
TiB_2	1173 and 1273	40 - 50	Dissolution of Ti and B in the matrix; low values for both $(a_{Ti})_{min}$ and $(a_B)_{min}$	Compatible
TiB	1173 and 1273	40 - 50	Dissolution of Ti and B in the matrix; low values for both $(a_{Ti})_{min}$ and $(a_B)_{min}$	Compatible
VB	1173 and 1273	40 - 50	Dissolution of V and B in the matrix; low values for both $(a_V)_{min}$ and $(a_B)_{min}$	Compatible
VB_2	1173 and 1273	40 - 50	Dissolution of V and B in the matrix; low values for both $(a_V)_{min}$ and $(a_B)_{min}$	Compatible
V_3B_2	1173 and 1273	40 - 50	Dissolution of V and B in the matrix; low values for $(a_B)_{min}$; high values for $(a_V)_{min}$	Compatibility depends on solubility of V in the matrix
V_2B_3	1173 and 1273	40 - 50	Dissolution of V and B in the matrix; low values for $(a_V)_{min}$ and $(a_B)_{min}$	Compatible
ZrB_2	1173 and 1273	40 - 50	Dissolution of Zr and B in the matrix; low values for $(a_{Zr})_{min}$ and $(a_B)_{min}$	Compatible

TABLE VI. - COMPATIBILITY OF FeAl ALLOYS WITH OXIDES

Reinforcement material	Temperature, K	Alloy composition, at % Al	Mode of reaction	Comments on compatibility
Al_2O_3	1173 and 1273	40 - 50	No reaction	Compatible
BeO	1173 and 1273	40 - 50	Dissolution of Be in the matrix; low values for $(a_{Be})_{min}$	Compatible
CaO	1173 and 1273	40 - 50	Formation of Al_2O_3 and $CaAl_2$	Not compatible
CeO_2	1173 and 1273	40 - 50	Formation of Al_2O_3 and Al_2Ce	Not compatible
Cr_2O_3	1173 and 1273	40 - 50	Formation of Al_2O_3 and free Cr	Not compatible
Gd_2O_3	1173 and 1273	40 - 50	Dissolution of Gd in the matrix; low values for $(a_{Gd})_{min}$	Compatible
HfO_2	1173 and 1273	40 - 50	Formation of Al_2O_3 and Al_2Hf	Not compatible
La_2O_3	1173 and 1273	40 - 50	Dissoltion of La in the matrix; low values for $(a_{La})_{min}$	Compatible
MgO[a]	1173 and 1273	40 - 50	Dissolution of Mg in the matrix; high values for $(a_{Mg})_{min}$	Compatibility depends on solubility of Mg in the matrix
MgO[b]	1173 and 1273	40 - 50	Formation of Al_2O_3 and Mg(g); high values for the partial pressure of Mg	Not compatible

[a]Closed system.
[b]Open system.

TABLE VI. - Concluded.

Reinforcement material	Temperature, K	Alloy composition, at % Al	Mode of reaction	Comments on compatibility
Sc_2O_3	1173 and 1273	40 - 50	Dissolution of Sc in the matrix; low values for $(a_{Sc})_{min}$	Compatible
SiO_2	1173 and 1273	40 - 50	Formation of Al_2O_3 and free Si	Not compatible
TiO	1173	40 - 50	Formation of Al_2O_3 and Fe_2Ti	Not compatible
	1273	40 - 41	Formation of Al_2O_3 and Fe_2Ti	Not compatible
		42 - 50	Formation of Al_2O_3 and TiAl	Not compatible
TiO_2	1173 and 1273	40 - 50	Formation of Al_2O_3 and free Ti	Not compatible
Y_2O_3	1173 and 1273	40 - 50	Dissolution of Y in the matrix; low values for $(a_Y)_{min}$	Compatible
ZrO_2	1173 and 1273	40 - 50	Formation of Al_2O_3 and Al_2Zr	Not compatible
Ca_2SiO_4	1173 and 1273	40 - 50	Formation of Al_2O_3 and free Si	Not compatible
$CaZrO_3$	1173 and 1273	40 - 50	Formation of Al_2O_3 and Al_2Zr	Not compatible
$Y_2O_3 \cdot 2ZrO_2$	1173 and 1273	40 - 50	Formation of Al_2O_3 and Al_2Zr	Not compatible

TABLE VII. - COMPATIBILITY OF FeAl ALLOYS WITH NITRIDES

Reinforcement material	Temperature, K	Alloy composition, at % Al	Mode of reaction	Comments on compatibility
AlN	1173 and 1273	40 - 50	No reaction	Compatible
BN	1173 and 1273	40 - 50	Formation of AlN and free B	Not compatible
HfN	1173 and 1273	40 - 50	Dissolution of Hf in the matrix; low values for $(a_{Hf})_{min}$	Compatible
LaN	1173 and 1273	40 - 50	Formation of AlN and $LaAl_2$	Not compatible
Si_3N_4	1173 and 1273	40 - 50	Formation of AlN and free Si	Not compatible
TaN	1173 and 1273	40 - 50	Formation of AlN and free Ta	Not compatible
TiN	1173	40 - 50	Dissolution of Ti in the matrix; low values for $(a_{Ti})_{min}$	Compatible
	1273	40 - 50	Dissolution of Ti in the matrix; high values for $(a_{Ti})_{min}$	Not compatible
ZrN	1173 and 1273	40 - 50	Formation of AlN and Al_2Zr	Not compatible

TABLE VIII. - COMPATIBILITY OF FeAl ALLOYS WITH SILICIDES

Reinforcement material	Temperature, K	Alloy composition, at % Al	Mode of reaction	Comments on compatibility
Cr_3Si and Cr_5Si_3	1173 and 1273	40 - 50	Dissolution of Cr and Si in the matrix; low values for $(a_{Si})_{min}$; high values for $(a_{Cr})_{min}$	Not compatible
Mo_3Si and Mo_5Si_3	1173 and 1273	40 - 50	Dissolution of Mo and Si in the matrix; low values for $(a_{Si})_{min}$; high values for $(a_{Mo})_{min}$	Compatibility depends on solubility of Mo in the matrix
$MoSi_2$	1173 and 1273	40 - 50	Dissolution of Mo and Si in the matrix; high values for both $(a_{Si})_{min}$ and $(a_{Mo})_{min}$	Compatibility depends on solubility of Mo and Si in the matrix
Nb_5Si_3 and $NbSi_2$	1173 and 1273	40 - 41	Formation of FeSi and Fe_2Nb	Not compatible
		42 - 50	Formation of FeSi and $NbAl_3$	Not compatible
Ta_2Si and Ta_5Si_3	1173 and 1273	40 - 50	Dissolution of Ta and Si in the matrix; low values for $(a_{Si})_{min}$; high values for $(a_{Ta})_{min}$	Compatibility depends on solubility of Ta in the matrix
$TaSi_2$	1173 and 1273	40 - 50	Formation of FeSi and free Ta	Not compatible
Ti_5Si_3 and TiSi	1173 and 1273	40 - 50	Dissolution of Ti and Si in the matrix; low values for both $(a_{Ti})_{min}$ and $(a_{Si})_{min}$	Compatible
V_3Si and V_5Si_3	1173 and 1273	40 - 50	Dissolution of V and Si in the matrix; low values for $(a_{Si})_{min}$; high values for $(a_V)_{min}$	Compatibility depends on solubility of V in the matrix
VSi_2	1173	40 - 50	Dissolution of V and Si in the matrix; low values for $(a_{Si})_{min}$; high values for $(a_V)_{min}$	Compatibility depends on solubility of V in the matrix
	1273	40 - 50	Dissolution of V and Si in the matrix; high values for both $(a_{Si})_{min}$ and $(a_V)_{min}$	Compatibility depends on solubility of V and Si in the matrix
W_5Si_3	1173 and 1273	40 - 50	Dissolution of W and Si in the matrix; high values for both $(a_W)_{min}$ and $(a_{Si})_{min}$	Compatibility depends on solubility of W and Si in the matrix
WSi_2	1173 and 1273	40 - 50	Formation of FeSi and free W	Not compatible
Zr_2Si	1173 and 1273	40 - 50	Formation of FeSi and Al_2Zr	Not compatible
Zr_5Si_3	1173 and 1273	40 - 50	Formation of FeSi and Al_2Zr	Not compatible
ZrSi	1173 and 1273	40 - 50	Formation of FeSi and Al_2Zr	Not compatible

TABLE IX. - COMPATIBLE CARBIDES IN ORDER OF INCREASING $(a_{Me})_{min}$ VALUES

[T = 1273 K; Me represents the metallic element of the carbide.]

Carbide	$(a_{Me})_{min}$ (Fe-40Al)	$(a_{Me})_{min}$ (Fe-50Al)
HfC	1.45×10^{-9}	2.23×10^{-9}
ZrC	4.29×10^{-8}	6.59×10^{-8}
TiC	1.84×10^{-7}	2.83×10^{-7}
TaC	2.90×10^{-6}	4.46×10^{-6}
Ta_2C	1.09×10^{-4}	1.34×10^{-4}
VC	3.10×10^{-4}	4.77×10^{-4}

TABLE X. - COMPATIBLE BORIDES IN ORDER OF INCREASING $(a_{Me})_{min}$ VALUES

[T = 1273 K; Me represents the metallic element of the boride.]

Boride	$(a_{Me})_{min}$, (Fe-40Al)	$(a_{Me})_{min}$, (Fe-50Al)
HfB_2	1.05×10^{-9}	6.37×10^{-10}
ScB_2	3.83×10^{-9}	2.31×10^{-9}
ZrB_2	7.45×10^{-9}	4.50×10^{-9}
TiB_2	3.92×10^{-7}	2.36×10^{-7}
TaB_2	1.22×10^{-4}	7.35×10^{-5}
TiB	2.34×10^{-4}	1.82×10^{-4}
VB_2	2.35×10^{-4}	1.42×10^{-4}
V_2B_3	2.95×10^{-4}	2.02×10^{-4}
VB	4.87×10^{-4}	3.78×10^{-4}

TABLE XI. - COMPATIBLE OXIDES IN ORDER OF INCREASING $(a_{Me})_{min}$ VALUES

[Me represents the metallic element of the oxide.]

Oxide	$(a_{Me})_{min}$, (Fe-40Al)	$(a_{Me})_{min}$, (Fe-50Al)
Y_2O_3	1.53×10^{-7}	2.12×10^{-7}
Sc_2O_3	2.15×10^{-7}	2.97×10^{-7}
Gd_2O_3	9.43×10^{-6}	1.30×10^{-5}
La_2O_3	2.24×10^{-5}	3.10×10^{-5}
BeO	4.30×10^{-4}	5.34×10^{-4}

TABLE XII. - COEFFICIENT OF THERMAL EXPANSION FOR COMPATIBLE REINFORCEMENT MATERIALS

[Coefficient of thermal expansion for FeAl at 1200 K is 21.8×10^{-6} K^{-1}.]

Reinforcement material	Coefficient of thermal expansion at 1200 K, K^{-1}
La_2O_3	16.3×10^{-6}
BeO	11.1
Sc_2O_3	10.8
Al_2O_3	9.6
Gd_2O_3	9.5
Y_2O_3	9.0
TiB_2	9.0
TiC	8.6
ZrC	8.1
ZrB_2	8.0
HfB_2	7.8
TaB_2	7.3
VC	7.3
HfC	7.2
TaC	7.1
AlN	6.3

APPENDIX A
GIBBS ENERGIES OF FORMATION OF COMPOUNDS AT 1173 AND 1273 K

Compound	$-\Delta G_f^o$ at 1173 K, kCal/mol	$-\Delta G_f^o$ at 1273 K, kCal/mol	Comments on thermodynamic data
Al_2Zr	40.8	40.8	ΔG_f^o same as of 1023 K, obtained from compilations by Hultgren et al. (ref. 1)
Al_3Zr_2	64.0	64.0	
Al_3Zr_4	72.1	72.1	
Al_3V	4.1	4.1	ΔG_f^o same as of 1273 K, obtained from compilations by Hultgren et al. (ref. 1)
Al_8V_5	19.6	19.6	
Al_4W	12.2	12.2	From Kaufman and Nesor (ref. 2)
Al_2Hf	40.8	40.8	Estimated to be the same as for Al_2Zr
AlB_{12}	50.6	50.5	
Al_4C_3	39.2	37.8	
AlN	46.4	43.8	
Al_2O_3	312.7	305.3	
BN	35.4	33.3	
B_4C	14.1	13.9	
BeO	118.0	115.7	
$CaAl_2$	47.6	47.1	
CaO	122.9	120.5	
Ca_2SiO_4	431.4	422.6	
$CaZrO_3$	341.1	334.3	
$CeAl_2$	39.4	39.0	
CeO_2	203.0	198.2	
CrB_2	26.0	25.8	
Cr_2O_3	196.1	190.1	
Cr_3Si	24.5	24.5	
Cr_5Si_3	57.9	57.4	
Cr_4Al_6	59.3	59.7	From Kaufman and Nesor (ref. 2)
FeB	16.0	15.9	
Fe_2B	15.9	15.6	
Fe_3C	0.3	0.6	
Fe_2Gd	8.3	8.3	ΔG_f^o same as ΔH_{298}^o, from Colinet and Pasturel (ref. 3)
Fe_3Gd	8.9	8.9	
$Fe_{17}Gd_2$	10.4	10.4	
Fe_2Hf	23.0	23.0	Estimated to be same as that for Fe_2Zr
Fe_3Mo_2	1.2	0.8	
$FeMo$	1.1	1.3	From Kaufman and Nesor (ref. 4)
Fe_4N	-12.1	-13.8	
Fe_2N	-12.8	-14.1	
Fe_2Nb	28.5	28.5	ΔG_f^o same as that at 1300 K, from Hultgren et al. (ref. 1)
$FeSi$	16.9	16.7	From Chart (ref. 5)
$FeTi$	7.6	7.1	
Fe_2Ti	16.7	16.0	
Fe_3W_2	6.5	6.1	
Fe_2Zr	23.0	23.0	ΔG_f^o same as 1023 K, obtained from Hultgren et al. (ref. 1)

Compound	$-\Delta G_f^o$ at 1173 K, kCal/mol	$-\Delta G_f^o$ at 1273 K, kCal/mol	Comments on thermodynamic data
Gd_2O_3	353.6	346.9	
HfB_2	76.9	76.6	
HfC	52.9	52.8	
HfN	63.9	61.9	
HfO_2	214.9	210.8	
$LaAl_2$	30.9	30.2	
LaB_6	95.6	95.6	ΔG_f^o same as ΔH_{298}^o, obtained from Topor and Kleppa (ref. 6)
LaN	41.8	39.4	
La_2O_3	349.6	343.2	
MgO	113.6	111.1	With reference to Mg(s) as the reference state
MgO	117.6	112.7	With reference to Mg(g) as the reference state
Mo_3Al	17.3	17.6	
MoAl	7.7	8.3	From Kaufman and Nesor (ref. 2)
Mo_2Al_3	20.0	21.4	
Mo_3Al_8	56.3	57.5	
Mo_2C	12.3	12.5	
Mo_3Si	28.0	28.0	
Mo_5Si_3	76.2	76.3	
$MoSi_2$	31.0	30.9	
Nb_3Al	32.0	31.0	
Nb_2Al	28.9	28.0	From Kaufman and Nesor (ref. 2)
$NbAl_3$	47.3	45.5	
NbB_2	39.0	38.8	
NbC	32.7	32.7	
Nb_2C	43.0	42.7	
Nb_5Si_3	111.5	111.8	
ScB_2	73.4	73.4	ΔG_f^o same as ΔH_f^o at 1600 K, from Topor and Kleppa (ref. 7)
Sc_2O_3	372.9	366.0	
SiC	13.9	13.6	
SiO_2	167.3	163.2	
Si_3N_4	85.1	77.2	
TaB_2	47.4	47.1	
TaC	33.5	33.6	
Ta_2C	47.6	47.6	
TaN	35.4	33.5	
Ta_2N	37.5	35.4	
Ta_5Si_3	84.0	84.4	
Ta_2Si	31.0	31.1	
$TaSi_2$	22.2	21.6	
TiAl	15.6	15.3	
Ti_3Al	16.4	15.6	
TiB	34.3	33.3	
TiB_2	62.2	61.7	
TiC	40.9	40.5	
TiN	54.3	52.1	
TiO	103.2	100.9	

Compound	$-\Delta G_f^o$ at 1173 K, kCal/mol	$-\Delta G_f^o$ at 1273 K, kCal/mol	Comments on thermodynamic data
TiO_2	174.7	170.4	
Ti_5Si_3	141.1	141.0	
$TiSi$	31.0	30.9	
$TiSi_2$	30.3	30.1	
VB	31.6	31.5	
VB_2	45.7	45.5	
V_3B_2	69.5	69.3	
V_2B_3	70.1	68.9	
V_2C	34.5	34.4	
VC	21.2	21.7	
VN	28.1	26.2	
V_3Si	34.4	34.2	
V_5Si_3	119.7	121.6	
VSi_2	33.9	34.2	
W_2C	18.0	19.0	
WC	8.4	8.4	
W_5Si_3	39.8	40.5	
WSi_2	20.2	20.0	
Y_2O_3	374.4	367.7	
$Y_2O_3 \cdot 2ZrO_2$	798.1	782.6	
ZrB_2	72.3	71.7	
ZrC	44.5	44.2	
ZrN	61.0	58.7	
ZrO_2	209.2	204.8	
Zr_2Si	50.1	49.8	
Zr_5Si_3	138.8	138.2	
$ZrSi$	36.6	36.4	
$ZrSi_2$	35.1	34.4	

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APPENDIX B
POSSIBLE STABLE PRODUCT COMPOUNDS IN THE MATRIX

The stable product compounds that can possibly be formed in the matrix as a result of interaction of FeAl alloys with different elements of the reinforcement materials are given in the following table:

Element	Temperature, K	Alloy composition, at % Al	Stable compound
B	1173/1273	40 - 50	FeB
C	1173/1273	40 - 50	Al_4C_3
Ca	1173/1273	40 - 50	Al_2Ca
Ce	1173/1273	40 - 50	Al_2Ce
Cr	1173/1273	40 - 50	Cr_4Al_6
Gd	1173/1273	40 - 50	Fe_2Gd
Hf	1173/1273	40 - 50	Al_2Hf
La	1173/1273	40 - 50	Al_2La
Mo	1173/1273	40 - 50	Mo_3Al
N	1173/1273	40 - 50	AlN
Nb	1173	40	Fe_2Nb
		41 - 50	$NbAl_3$
	1273	40 - 41	Fe_2Nb
		42 - 50	$NbAl_3$
O	1173/1273	40 - 50	Al_2O_3
Sc	(a)	(a)	(a)
Si	1173/1273	40 - 50	FeSi
Ta	(b)	(b)	(b)
Ti	1173	40 - 50	Fe_2Ti
	1273	40 - 41	Fe_2Ti
		42 - 50	TiAl
V	(c)	(c)	(c)
W	(d)	(d)	(d)
Y	(e)	(e)	(e)
Zr	1173/1273	40 - 50	Al_2Zr

[a]No thermodynamic data on FeSc or AlSc compounds.
[b]No thermodynamic data on FeTa or AlTa compounds.
[c]No stable compounds in the FeAl matrix.
[d]No stable compounds in the FeAl matrix.
[e]No thermodynamic data for AlY compounds.

APPENDIX C
MINIMUM ACTIVITIES OF ELEMENTS OF REINFORCEMENT MATERIALS IN THE MATRIX

This appendix gives the minimum calculated values for the elements of the reinforcement materials in the matrix for two alloy compositions, i.e., 40 and 50 at % Al. The activities will be given only for those reinforcement materials for which thermodynamic calculations have shown that dissolution of elements of the reinforcement material in the matrix is the predominant mode of reaction.

HfC

X_{Al}	$(a_{Hf})_{min}$, 1173 K	$(a_C)_{min}$, 1173 K	$(a_{Hf})_{min}$, 1273 K	$(a_C)_{min}$, 1273 K
0.4	2.23×10^{-10}	2.55×10^{-6}	1.45×10^{-9}	1.07×10^{-5}
0.5	3.40×10^{-10}	4.81×10^{-6}	2.23×10^{-9}	2.04×10^{-5}

Mo_2C

X_{Al}	$(a_{Mo})_{min}$, 1173 K	$(a_C)_{min}$, 1173 K	$(a_{Mo})_{min}$, 1273 K	$(a_C)_{min}$, 1273 K
0.4	0.09	0.05	0.11	0.08
0.5	0.11	0.07	0.14	0.10

NbC

X_{Al}	$(a_{Nb})_{min}$, 1173 K	$(a_C)_{min}$, 1173 K	$(a_{Nb})_{min}$, 1273 K	$(a_C)_{min}$, 1273 K
0.4	1.31×10^{-6}	7.66×10^{-3}	4.05×10^{-6}	0.01
0.5	2.00×10^{-6}	0.014	6.23×10^{-6}	0.02

TaC

X_{Al}	$(a_{Ta})_{min}$, 1173 K	$(a_C)_{min}$, 1173 K	$(a_{Ta})_{min}$, 1273 K	$(a_C)_{min}$, 1273 K
0.4	9.28×10^{-7}	5.58×10^{-7}	2.9×10^{-6}	1.7×10^{-6}
0.5	1.41×10^{-6}	5.58×10^{-7}	4.5×10^{-6}	1.7×10^{-6}

Ta_2C

X_{Al}	$(a_{Ta})_{min}$, 1173 K	$(a_C)_{min}$, 1173 K	$(a_{Ta})_{min}$, 1273 K	$(a_C)_{min}$, 1273 K
0.4	4.79×10^{-5}	1.36×10^{-9}	1.09×10^{-4}	6.80×10^{-9}
0.5	5.92×10^{-5}	1.36×10^{-9}	1.34×10^{-4}	6.80×10^{-9}

TiC

X_{Al}	$(a_{Ti})_{min}$, 1173 K	$(a_C)_{min}$, 1173 K	$(a_{Ti})_{min}$, 1273 K	$(a_C)_{min}$, 1273 K
0.4	3.97×10^{-8}	1.50×10^{-6}	1.84×10^{-7}	3.38×10^{-6}
0.5	6.06×10^{-8}	5.75×10^{-7}	2.83×10^{-7}	2.19×10^{-6}

V_2C

X_{Al}	$(a_V)_{min}$, 1173 K	$(a_C)_{min}$, 1173 K	$(a_V)_{min}$, 1273 K	$(a_C)_{min}$, 1273 K
0.4	7.86×10^{-4}	3.77×10^{-7}	1.44×10^{-3}	1.23×10^{-6}
0.5	9.72×10^{-4}	3.77×10^{-7}	1.78×10^{-3}	1.23×10^{-6}

VC

X_{Al}	$(a_V)_{min}$, 1173 K	$(a_C)_{min}$, 1173 K	$(a_V)_{min}$, 1273 K	$(a_C)_{min}$, 1273 K
0.4	1.32×10^{-4}	8.05×10^{-5}	3.10×10^{-4}	1.85×10^{-4}
0.5	2.02×10^{-4}	8.05×10^{-5}	4.77×10^{-4}	1.85×10^{-4}

W_2C

X_{Al}	$(a_W)_{min}$, 1173 K	$(a_C)_{min}$, 1173 K	$(a_W)_{min}$, 1273 K	$(a_C)_{min}$, 1273 K
0.4	0.03	4.46×10^{-4}	0.03	5.44×10^{-4}
0.5	0.03	4.46×10^{-4}	0.04	5.44×10^{-4}

WC

X_{Al}	$(a_W)_{min}$, 1173 K	$(a_C)_{min}$, 1173 K	$(a_W)_{min}$, 1273 K	$(a_C)_{min}$, 1273 K
0.4	0.04	0.03	0.06	0.04
0.5	0.07	0.03	0.09	0.04

ZrC

X_{Al}	$(a_{Zr})_{min}$, 1173 K	$(a_C)_{min}$, 1173 K	$(a_{Zr})_{min}$, 1273 K	$(a_C)_{min}$, 1273 K
0.4	8.45×10^{-9}	9.70×10^{-5}	4.29×10^{-8}	3.16×10^{-4}
0.5	1.29×10^{-8}	1.83×10^{-4}	6.59×10^{-8}	6.04×10^{-4}

CrB_2

X_{Al}	$(a_{Cr})_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_{Cr})_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	0.63	3.75×10^{-3}	0.55	6.03×10^{-3}
0.5	0.38	3.75×10^{-3}	0.33	6.03×10^{-3}

HfB_2

X_{Al}	$(a_{Hf})_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_{Hf})_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	2.07×10^{-10}	9.35×10^{-6}	1.05×10^{-9}	2.93×10^{-6}
0.5	1.27×10^{-10}	1.28×10^{-5}	6.37×10^{-10}	4.06×10^{-5}

LaB_6

X_{Al}	$(a_{La})_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_{La})_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	1.34×10^{-4}	2.72×10^{-3}	1.34×10^{-4}	4.40×10^{-3}
0.5	3.04×10^{-5}	3.03×10^{-3}	2.95×10^{-5}	4.91×10^{-3}

ScB_2

X_{Al}	$(a_{Sc})_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_{Sc})_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	9.41×10^{-10}	1.46×10^{-7}	3.83×10^{-9}	5.03×10^{-7}
0.5	5.74×10^{-10}	1.46×10^{-7}	2.31×10^{-9}	5.03×10^{-7}

TaB_2

X_{Al}	$(a_{Ta})_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_{Ta})_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	6.63×10^{-5}	3.85×10^{-5}	1.22×10^{-4}	8.95×10^{-5}
0.5	4.04×10^{-5}	3.85×10^{-5}	7.35×10^{-5}	8.95×10^{-5}

TiB_2

X_{Al}	$(a_{Ti})_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_{Ti})_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	1.14×10^{-7}	1.26×10^{-5}	3.92×10^{-7}	2.82×10^{-5}
0.5	6.93×10^{-8}	9.83×10^{-5}	2.36×10^{-7}	2.29×10^{-5}

TiB

X_{Al}	$(a_{Ti})_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_{Ti})_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	8.63×10^{-5}	2.54×10^{-5}	2.35×10^{-4}	5.86×10^{-5}
0.5	6.75×10^{-5}	1.55×10^{-5}	1.82×10^{-4}	3.88×10^{-5}

VB

X_{Al}	$(a_V)_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_V)_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	2.73×10^{-4}	1.29×10^{-6}	4.87×10^{-4}	3.95×10^{-6}
0.5	2.13×10^{-4}	1.29×10^{-6}	3.78×10^{-4}	3.95×10^{-6}

VB_2

X_{Al}	$(a_V)_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_V)_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	1.33×10^{-4}	5.47×10^{-5}	2.35×10^{-4}	1.24×10^{-4}
0.5	8.13×10^{-5}	5.47×10^{-5}	1.42×10^{-4}	1.24×10^{-4}

V_3B_2

X_{Al}	$(a_V)_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_V)_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	1.69×10^{-3}	3.32×10^{-7}	2.69×10^{-3}	1.13×10^{-6}
0.5	1.44×10^{-3}	3.32×10^{-7}	2.27×10^{-3}	1.13×10^{-6}

V_2B_3

X_{Al}	$(a_V)_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_V)_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	1.64×10^{-4}	1.43×10^{-5}	2.95×10^{-4}	3.63×10^{-5}
0.5	1.13×10^{-4}	1.43×10^{-5}	2.02×10^{-4}	3.63×10^{-5}

ZrB_2

X_{Al}	$(a_{Zr})_{min}$, 1173 K	$(a_B)_{min}$, 1173 K	$(a_{Zr})_{min}$, 1273 K	$(a_B)_{min}$, 1273 K
0.4	1.50×10^{-9}	2.50×10^{-5}	7.45×10^{-9}	7.80×10^{-5}
0.5	9.13×10^{-10}	3.45×10^{-5}	4.49×10^{-9}	1.08×10^{-4}

BeO

X_{Al}	$(a_{Be})_{min}$, 1173 K	$(a_{Be})_{min}$, 1273 K
0.4	2.12×10^{-4}	4.31×10^{-4}
0.5	2.63×10^{-4}	5.34×10^{-4}

Gd_2O_3

X_{Al}	$(a_{Gd})_{min}$, 1173 K	$(a_{Gd})_{min}$, 1273 K
0.4	3.43×10^{-6}	9.43×10^{-6}
0.5	4.71×10^{-6}	1.30×10^{-5}

La_2O_3

X_{Al}	$(a_{La})_{min}$, 1173 K	$(a_{La})_{min}$, 1273 K
0.4	8.83×10^{-6}	2.24×10^{-5}
0.5	1.21×10^{-5}	3.10×10^{-5}

MgO

[Closed system.]

X_{Al}	$(a_{Mg})_{min}$, 1173 K	$(a_{Mg})_{min}$, 1273 K
0.4	1.75×10^{-3}	3.62×10^{-3}
0.5	2.16×10^{-3}	4.49×10^{-3}

MgO

[Open system.]

X_{Al}	(p_{Mg}), 1173 K	(p_{Mg}), 1273 K
0.4	2.46×10^{-4}	1.44×10^{-3}
0.5	3.04×10^{-4}	1.78×10^{-3}

Sc_2O_3

X_{Al}	$(a_{Sc})_{min}$, 1173 K	$(a_{Sc})_{min}$, 1273 K
0.4	5.35×10^{-8}	2.15×10^{-7}
0.5	7.36×10^{-8}	2.97×10^{-7}

Y_2O_3

XAl	$(a_Y)_{min}$, 1173 K	$(a_Y)_{min}$, 1273 K
0.4	3.92×10^{-8}	1.54×10^{-7}
0.5	5.39×10^{-8}	2.12×10^{-7}

HfN

X_{Al}	$(a_{Hf})_{min}$, 1173 K	$(a_{Hf})_{min}$, 1273 K
0.4	1.16×10^{-5}	2.68×10^{-5}
0.5	1.59×10^{-5}	3.70×10^{-5}

TiN

X_{Al}	$(a_{Ti})_{min}$, (1173 K)	$(a_{Ti})_{min}$, 1273 K
0.4	7.11×10^{-4}	1.32×10^{-3}
0.5	9.77×10^{-4}	1.83×10^{-3}

Cr_3Si

X_{Al}	$(a_{Cr})_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_{Cr})_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	0.20	2.69×10^{-5}	0.22	6.31×10^{-5}
0.5	0.18	2.69×10^{-5}	0.20	6.31×10^{-5}

Cr_5Si_3

X_{Al}	$(a_{Cr})_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_{Cr})_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	0.23	2.91×10^{-4}	0.23	5.21×10^{-4}
0.5	0.20	2.91×10^{-4}	0.20	5.21×10^{-4}

Mo_3Si

X_{Al}	$(a_{Mo})_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_{Mo})_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	0.12	2.17×10^{-4}	0.14	5.60×10^{-4}
0.5	0.11	2.98×10^{-4}	0.13	7.74×10^{-4}

Mo_5Si_3

X_{Al}	$(a_{Mo})_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_{Mo})_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	0.04	1.36×10^{-4}	0.05	3.16×10^{-4}
0.5	0.04	1.63×10^{-4}	0.04	3.78×10^{-4}

$MoSi_2$

X_{Al}	$(a_{Mo})_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_{Mo})_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	0.15	2.34×10^{-3}	0.14	4.00×10^{-3}
0.5	0.09	2.47×10^{-3}	0.08	4.22×10^{-3}

Ta_2Si

X_{Al}	$(a_{Ta})_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_{Ta})_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	0.02	1.68×10^{-6}	0.03	4.56×10^{-6}
0.5	0.02	1.68×10^{-6}	0.02	4.56×10^{-6}

Ta_5Si_3

X_{Al}	$(a_{Ta})_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_{Ta})_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	0.02	6.07×10^{-6}	0.03	1.48×10^{-5}
0.5	0.02	6.07×10^{-6}	0.02	1.48×10^{-5}

Ti_5Si_3

X_{Al}	$(a_{Ti})_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_{Ti})_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	1.68×10^{-4}	1.66×10^{-6}	3.00×10^{-4}	5.25×10^{-5}
0.5	1.45×10^{-4}	7.33×10^{-7}	2.58×10^{-4}	1.29×10^{-6}

$TiSi$

X_{Al}	$(a_{Ti})_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_{Ti})_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	5.12×10^{-4}	1.05×10^{-4}	8.04×10^{-4}	1.52×10^{-4}
0.5	4.00×10^{-4}	6.42×10^{-5}	6.24×10^{-4}	1.00×10^{-4}

V_3Si

X_{Al}	$(a_V)_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_V)_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	0.05	3.81×10^{-7}	0.06	1.34×10^{-6}
0.5	0.04	3.81×10^{-7}	0.06	1.34×10^{-6}

V_5Si_3

X_{Al}	$(a_V)_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_V)_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	1.06×10^{-3}	3.66×10^{-8}	1.45×10^{-3}	1.10×10^{-7}
0.5	9.20×10^{-4}	3.66×10^{-8}	1.25×10^{-3}	1.10×10^{-7}

VSi_2

X_{Al}	$(a_V)_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_V)_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	0.04	6.94×10^{-4}	0.04	1.15×10^{-3}
0.5	0.03	6.94×10^{-4}	0.02	1.15×10^{-3}

W_5Si_3

X_{Al}	$(a_W)_{min}$, 1173 K	$(a_{Si})_{min}$, 1173 K	$(a_W)_{min}$, 1273 K	$(a_{Si})_{min}$, 1273 K
0.4	1	3.36×10^{-3}	0.88	4.82×10^{-3}
0.5	0.87	3.36×10^{-3}	0.76	4.82×10^{-3}

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16. Abstract

Chemical compatibility of several reinforcement materials with FeAl alloys within the concentration range 40 to 50 at % Al have been analyzed from thermodynamic considerations at 1173 and 1273 K. The reinforcement materials considered in this study include carbides, borides, oxides, nitrides, and silicides. Although several chemically compatible reinforcement materials have been identified in this study, the coefficients of thermal expansion for none of these materials match closely with that of FeAl alloys and this might pose serious problems in the design of composite systems based on FeAl alloys.

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