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The 500°C isothermal section of the Al–Dy–Ti ternary system

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Abstract

The phase relations in the Al–Dy–Ti ternary system at 500°C were investigated by powder X-ray diffraction (XRD), differential thermal analysis (DTA), optical microscopy and scanning electron microscopy (SEM) techniques. The existence of two ternary compounds $DyTi_2Al_{20}$ and $Dy_6Ti_4Al_{43}$ were confirmed. The 500°C isothermal section of this ternary system consists of 14 single-phase regions, 27 two-phase regions and 14 three-phase regions. At 500°C, the maximum solid solubilities of Ti in Dy_2Al, Dy_3Al_2 and $DyAl_2$ is about 2.1at.%, 3.6at.%, 16.5at.%, respectively, and that of Dy in Ti, Ti_3Al, TiAl is less than 1at.%.

Keywords: Rare earth compounds; Transition metal compounds; Crystal structure; X-ray diffraction; Phase diagram

1. Introduction

The good high-temperature properties, low density and oxidation resistance of titanium aluminides suggest their widespread applications as attractive candidates in advanced aerospace engine and airframe components [1,2]. However, their application is hindered by low ductility and toughness at ambient temperature. Refs. [3,4] revealed that some alloying additions such as Cr, V and rare earth elements may improve the room temperature ductility of titanium aluminides. As a contribution of our systematic study of the Al–RE–Ti system [5–7], this present paper concerns the 500°C isothermal section of the phase diagram of the Al–Dy–Ti ternary system.

The binary Al–Ti system is taken from Ref. [8] and Al–Dy, Dy–Ti systems are accepted from Ref. [9]. At 500°C there are four intermetallic compounds in the Al–Ti system, namely Ti_3Al, TiAl, $TiAl_2$, and $TiAl_3$, respectively, and five intermetallic compounds in the Al–Dy system, namely $DyAl_3$, $DyAl_2$, DyAl, Dy_3Al_2, and Dy_2Al, respectively. No intermetallic phase was found in the Dy–Ti binary system. Crystallographic data of the binary phases are taken from Refs. [8–11].

Zhang et al. [12] studied the 1000°C partial isothermal section of the phase diagram of the Al–Dy–Ti ternary system by means of the diffusion triple method and electron probe microanalysis. Two pseudobinary intermetallics with considerably extensive homogeneity ranges, namely $Dy(Ti_{1-x}Al_x)_2$ ($x=70$–100%) and $Dy_2(Ti_{1-x}Al_x)$ ($x=90$–100%) were found.

Of the ternary phase, two compounds $DyTi_2Al_{20}$ [13] and $Dy_6Ti_4Al_{43}$ [14] have been identified by Niemann et al. Compound $DyTi_2Al_{20}$ crystallizes with the cubic $CeCr_2Al_{20}$ type structure (space group $Fd3m$) and compound $Dy_6Ti_4Al_{43}$ crystallizes with the hexagonal $Ho_6Mo_4Al_{43}$ type structure (space group $P6_3/mcm$).

2. Experimental

One hundred and forty samples, each weighing 2 g, were prepared starting from high purity metal blocks (purity >99.9 mass%) of Dy, Ti and Al. All samples were prepared by arc melting three times under high purity argon and sealed in evacuated quartz tubes for homogenization annealing. The heat treatment temperature was determined by differential thermal analysis (DTA) results of some alloys or based on the previous work of binary systems. The Al-rich alloys were kept at 600°C for 1440 h, the other samples were homogenized at 900°C for 720 h.

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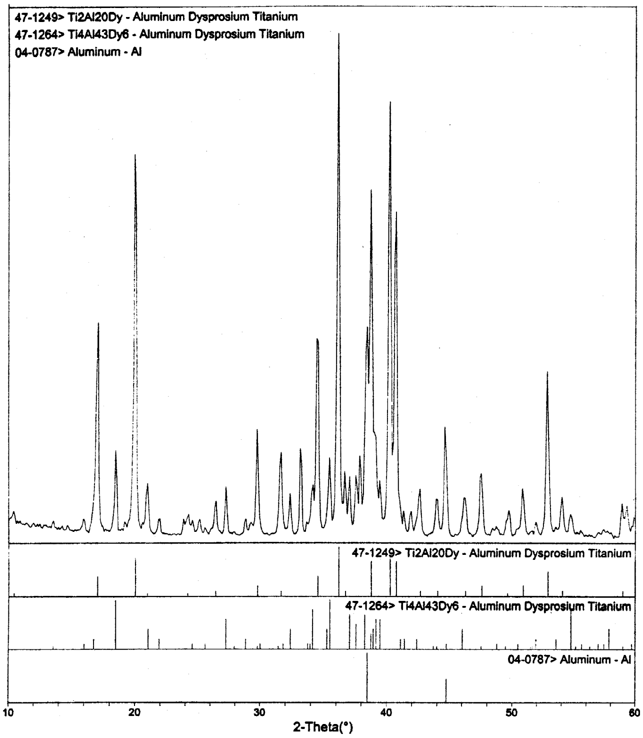

Fig. 1. X-ray diffraction (XRD) pattern of alloy no. 13 (Dy4Ti6Al90).

Then the samples were cooled at a rate of 10 K/h to 500°C and kept at 500°C for 170 h. At last, the samples were quenched into an ice-water mixture.

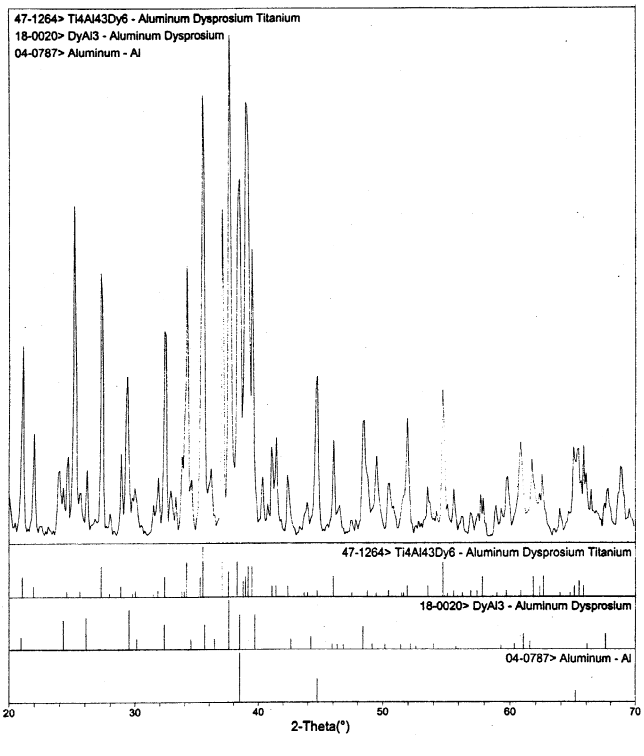

Fig. 2. X-ray diffraction (XRD) pattern of alloy no. 11 (Dy12Ti4Al84).

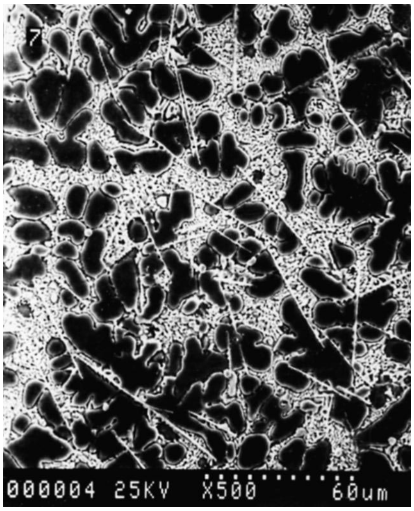

Fig. 3. Microstructure of alloy no. 6 (Dy6Ti50Al44) annealed at 900°C, 720 h and 500°C, 170 h; magnification ×500; Grey matrix: TiAl; black: Ti_3Al; bacillary: DyAl.

The samples for X-ray diffraction (XRD) analysis were powdered and annealed in vacuum glass tubes at 500°C for 4 days, then quenched into liquid nitrogen. The X-ray diffraction analysis was performed on a Rigaku 3105 X-ray diffractometer (MoKα, Zr filter) and on a Rigaku D/Max 2500PC X-ray diffractometer (CuKα_1, monochromator) using JADE5 software [15]. The metallographic analyses were performed on S-570 scanning electron microscope on selected alloys, which were polished and etched by standard methods.

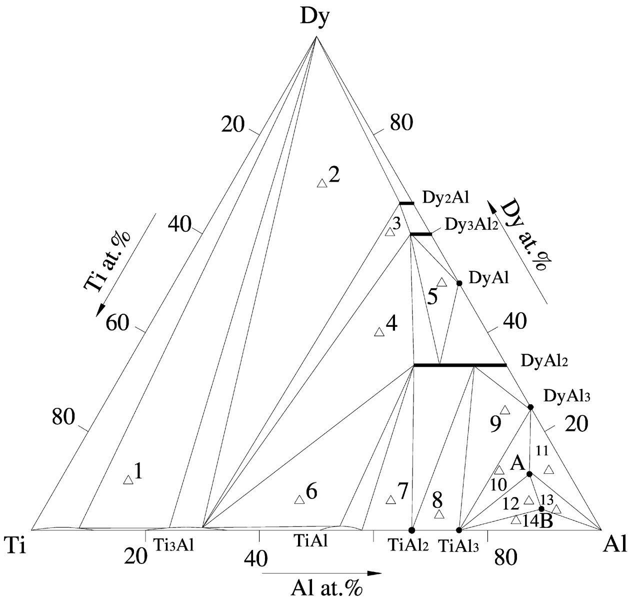

Fig. 4. The isothermal section of the Al–Dy–Ti ternary system at 500°C (A) $Dy_6Ti_4Al_{43}$; (B) $DyTi_2Al_{20}$; (△) three-phase region.

Table 1
Compositions and XRD identified phases in Al–Dy–Ti alloys annealed at 500°C

Alloy no.	Nominal composition in at.%	XRD identified phases
1	Dy10Ti78Al12	$Dy+Ti+Ti_3Al$
2	Dy70Ti14Al16	$Dy+ Dy_2Al +Ti_3Al$
3	Dy60Ti7Al33	$Dy_2Al+Dy_3Al_2+Ti_3Al$
4	Dy40Ti19Al41	$Dy_3Al_2+Ti_3Al+ DyAl_2$
5	Dy50Ti3Al47	$Dy_3Al_2+DyAl+ DyAl_2$
6	Dy6Ti50Al44	$Ti_3Al+ DyAl_2+TiAl$
7	Dy6Ti34Al60	$TiAl_2+ DyAl_2+TiAl$
8	Dy3Ti27Al70	$TiAl_2+ DyAl_2+TiAl_3$
9	Dy24Ti5Al71	$TiAl_3+ DyAl_2+DyAl_3$
10	Dy12Ti12Al76	$TiAl_3+ DyAl_3+ Dy_6Ti_4Al_{43}$
11	Dy12Ti4Al84	$DyAl_3+ Dy_6Ti_4Al_{43}+Al$
12	Dy6Ti10Al84	$DyTi_2Al_{20}+ Dy_6Ti_4Al_{43}+ TiAl_3$
13	Dy4Ti6Al90	$DyTi_2Al_{20}+ Dy_6Ti_4Al_{43}+Al$
14	Dy2Ti14Al84	$DyTi_2Al_{20}+Al+TiAl_3$

3. Results and discussion

3.1. Phase analysis

In the Al–Dy–Ti ternary system, nine binary compounds, namely Ti_3Al, TiAl, $TiAl_2$, $TiAl_3$, $DyAl_3$, $DyAl_2$, DyAl, Dy_3Al_2, Dy_2Al [8–11], and two ternary compounds $DyTi_2Al_{20}$ [13] and $Dy_6Ti_4Al_{43}$ [14] were reported, all but compound Dy_2Al [16] have their JCPDS PDF cards. With the crystallographic data of Dy_2Al taken from Ref. [16], using the LAZY program [17], we were able to obtain the calculated XRD pattern of the compound Dy_2Al. The results of XRD analysis of our alloy samples are in good agreement with the respective JCPDS PDF cards and the calculated Dy_2Al XRD pattern; thus the existence of these 11 phases was confirmed.

Pop et al. [18] reported a hexagonal binary compound Dy_2Al_{17} with Th_2Ni_{17} structure type (space group $P6_3/mmc$, $a=11.788$ Å, $c=11.322$ Å) in the Al–Dy system. In order to identify this phase, we prepared a series of alloy samples in the Al-rich region of the Al–Dy–Ti system. The calculated XRD pattern of Dy_2Al_{17} was obtained by applying the LAZY program [17] on the basis of crystallographic data taken from Ref. [18]. By analyzing the XRD patterns of these samples with JCPDS PDF cards and the calculated XRD pattern of Dy_2Al_{17}, we were able to identify the phases in each samples. Figs. 1–2 show the XRD patterns of two selected alloy samples, indicated the existence of two ternary compounds $DyTi_2Al_{20}$ and $Dy_6Ti_4Al_{43}$, no evidence was found to confirm the existence of Dy_2Al_{17} under our experimental conditions.

To find possible ternary compounds in the region adjoining the duplex alloy $\alpha_2Ti_3Al+\gamma TiAl$, a set of samples were prepared. The XRD results of these samples show the existence of a three-phase region of $Ti_3Al+DyAl_2+TiAl$. The SEM photomicrography of alloy no. 6 (Dy6Ti50Al44) in Fig. 3 clearly shows the three-phase equilibrium, indicating that there are no new ternary compounds in this region.

3.2. Isothermal section at 500°C

From the combination of XRD analysis, optical microscopy and SEM results of 140 alloy samples, we come to the conclusion that no new ternary compound was found in this system at 500°C. The phase relations in the Al–Dy–Ti ternary system are shown in Fig. 4. The nominal compositions and XRD-identified phases in some selected

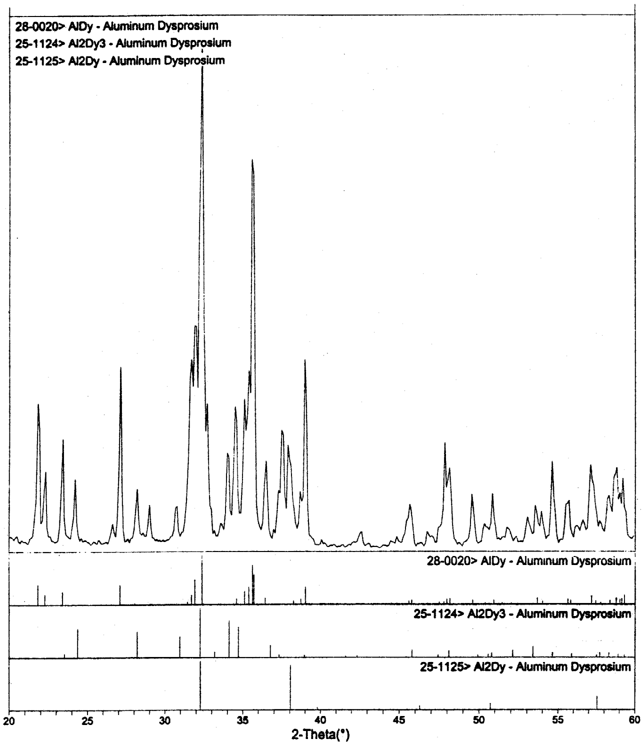

Fig. 5. X-ray diffraction (XRD) pattern of alloy no. 5 (Dy50Ti3Al47).

samples are shown in Table 1. The three-phase region $Dy_3Al_2+DyAl+DyAl_2$ is somewhat special. The XRD pattern of alloy no. 5 which falls in this region is shown in Fig. 5. The isothermal section of the Al–Dy–Ti ternary system at 500°C consists of 14 single-phase regions, 27 two-phase regions, and 14 three-phase regions. Six solid solution regions were observed in this system. The maximum solid solubility of Ti in Dy_2Al, Dy_3Al_2 and $DyAl_2$ is found to be 2.1at.%, 3.6at.% and 16.5at.%, respectively, at 500°C. The single phase ranges extend parallel to the Ti–Al line, which means that a certain amount of Al atoms are replaced by Ti in the Dy_2Al, Dy_3Al_2 and $DyAl_2$ compounds. The maximum solid solubility of Dy in Ti, Ti_3Al and TiAl, as observed from SEM and XRD data, does not exceed 1at.% Dy. No solubility of Ti in DyAl and $DyAl_3$ are detected in our work.

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