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Letter

High temperature thermal expansion characteristics of Ni_3Al alloys

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Abstract

The thermal expansion of Ni_3Al alloys with and without ternary additions have been investigated with the aid of a dilatometer. The Ni_3Al alloys were studied over the temperature range 25–1000 °C. The coefficient of thermal expansion α of all the aluminides studied in this investigation varies linearly with the temperature. The coefficient of thermal expansion of Ni_3Al is found to show an increase with the decrease in Al content from stoichiometric composition. B and Zr additions decrease the value α of Ni_3Al alloys at room temperature while Hf and Ti additions do not alter it significantly.

1. Introduction

The nickel aluminide Ni_3Al is an intermetallic compound and is known to have superior strength properties for application at elevated temperatures [1]. The emergence of Ni_3Al alloys as practical high-temperature materials has prompted renewed interest in research that necessitates understanding the physical and mechanical properties of these materials. Even though studies on a variety of mechanical properties of Ni_3Al and its alloys have been conducted at room temperature and at elevated temperatures, limited work on the physical properties of these materials has been reported. Since thermal expansion is an important design factor, it is of interest to study thermal expansion characteristics of Ni_3Al alloys for a better understanding of alloying behaviour.

It was shown that among the nickel aluminides, the intermetallic compound Ni_3Al has the lowest coefficient of thermal expansion [2]. Arbuzov and Zelenkov [3] observed a reduction in the coefficient of thermal expansion of Ni_3Al between 480 and 550 °C, while Maniar and Bridge [4] observed linear variation with temperature. In our earlier study [5] of Ni_3Al by high-temperature X-ray diffraction and dilatometry, no anomaly in the thermal expansion was observed. Dilatometric study was reported on the thermal expansion coefficient α of Ni_3Al and the effect of the addition of the alloying elements (V, Ti, Cr, Mn, Zr, Ta) between 100 and 900 °C [3]. The effect of the addition of iron on the value of α of Ni_3Al was studied by X-ray diffraction [6]. Low-temperature thermal expansion of Ni_3Al was reported by Kortekaas *et al.* [7]. There are no reported experimental data on the thermal expansion of off-stoichiometric Ni_3Al phase alloys. In the present work, we report on a study of the thermal expansion characteristics of pure Ni_3Al phase alloys and the effect of ternary additions, B, Hf, Zr and Ti.

2. Experimental details

The alloys were prepared by non-consumable arc melting under argon atmosphere using high purity (99.9%+) metals Ni, Al, Hf, Zr and Ti and the NiB master alloy. The melting was repeated at least five times to ensure chemical homogeneity. The nominal compositions of the aluminides were calculated based on the formula $[Ni_3(Al_{1-y}C_y)]B_x$, where C is the ternary element, y is the atom fraction of the ternary element and x is the atom fraction of boron. The compositions of the Hf, Zr and Ti-containing alloys were all within the solubility limits of the $L1_2$ phase fields in their respective ternary phase diagrams. The alloy composition was determined by instrumental methods and a wet chemical method. The elements Al and Ti were analysed by atomic absorption spectroscopy and the contents of B, Hf and Zr were determined by d.c. plasma emission spectrometry. Table 1 lists the chemical compositions of the aluminides.

All the ingots were sealed in quartz tubes under 1×10^{-5} Torr vacuum and homogenized for 60 h at 1000 °C and then air cooled to room temperature. The microstructures of the homogenized alloys were examined using an optical microscope for structural details such as grain boundaries and the presence of a second phase, if any. All the alloys were found to be in single phase, except the alloy containing 1.76 at.% B. The specimens prepared for microscopic examination were examined by X-ray diffraction to obtain information

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TABLE 1. Chemical analysis and thermal expansion values of the nickel aluminides

Alloy	Chemical composition (at.%)					Coefficient of thermal expansion[a] $\times 10^6$ (°C^{-1})
	Al	B	Hf	Zr	Ti	
Ni_3Al (23.3 at.% Al)	23.3	–	–	–	–	13.80
Ni_3Al (23.9 at.% Al)	23.9	–	–	–	–	13.40
Ni_3Al (25.0 at.% Al)	25.0	–	–	–	–	13.20
NAB-1	23.2	0.20	–	–	–	13.99
NAB-2	23.8	0.42	–	–	–	13.66
NAB-3	23.8	0.75	–	–	–	13.41
NAB-4	24.0	0.98	–	–	–	12.74
NAB-5	23.7	1.22	–	–	–	12.39
NAB-6	23.0	1.76	–	–	–	14.03
NABH-1	23.5	0.24	0.50	–	–	13.23
NABH-2	23.3	0.24	0.73	–	–	13.49
NABH-3	23.1	0.19	0.98	–	–	13.18
NABZ-1	23.4	0.26	–	0.52	–	13.49
NABZ-2	23.2	0.18	–	0.71	–	13.25
NABZ-3	23.0	0.15	–	1.13	–	12.85
NABT-1	19.5	0.25	–	–	4.5	13.55

[a] At room temperature.

about the homogeneity of the alloys and the phases present. X-ray scans were made with a scanning speed of 1° min^{-1} on a PW 1730 X-ray diffractometer using Cu Kα radiation. Sharp reflections of the X-ray diffraction patterns indicate the homogeneity of the samples.

Dilatometer measurements were made using an Orton automatic recording dilatometer. Specimens of cylindrical shape and with a length of 2.54 cm were cut out of the homogenized buttons. The dilatometer specimens were annealed at 900 °C for 2 h under 1×10^{-5} Torr vacuum to relieve stresses that might have been introduced during machining of the samples. The system was evacuated to 1×10^{-5} Torr vacuum and the recording was done using these specimens at a heating rate of 2.5 °C min^{-1}. Displacement measurements were made using a linear variable displacement transducer and a silica push rod system. Temperature changes with time were electronically programmed and controlled, and the specimen temperature was estimated to be uniform and accurate to within ±3 °C. The curve of the percentage linear thermal expansion *vs.* temperature was drawn from room temperature to 1000 °C using a recorder. The coefficient of thermal expansion α of the test specimen was calculated using the relation

$$\alpha=\{1/(T_2-T_1)\}\{(\Delta L_{T_2}/L_0)-(\Delta L_{T_1}/L_0)\}(1/100) \qquad (1)$$

where $\Delta L_{T_2}/L_0$ and $\Delta L_{T_1}/L_0$ are the percentage linear thermal expansion values at temperatures T_2 and T_1 respectively with a difference of 50 °C successively and α was assigned to the average temperature $0.5(T_2+T_1)$.

To establish the accuracy of the dilatometer, the coefficient of thermal expansion of spectroscopically pure copper was determined from room temperature to 1000 °C. The measured α values were within 2% of the reported standard thermal expansion values [8].

3. Results and discussion

Figure 1 gives the coefficient of thermal expansion of Ni_3Al phase alloys as a function of temperature and

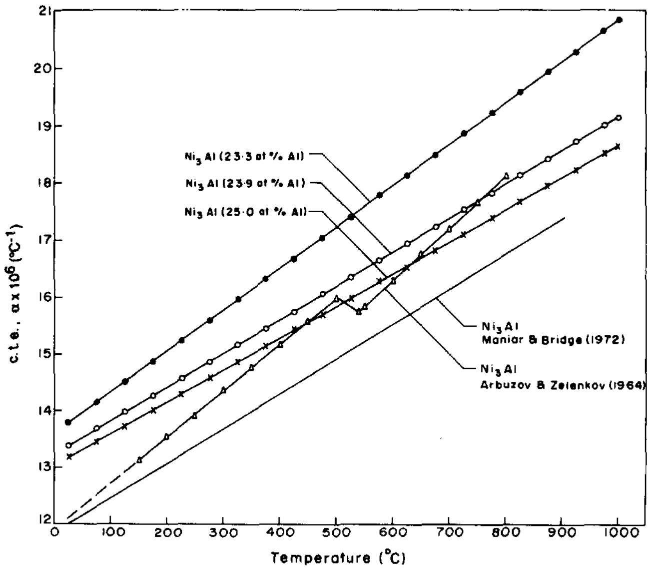

Fig. 1. Temperature dependence of the coefficient of thermal expansion of Ni_3Al phase alloys.

the thermal expansion data of Ni_3Al reported in the literature [3, 4]. The coefficient of thermal expansion of Ni_3Al phase alloys varies with the composition of Al. With the decrease in Al content from stoichiometric composition, the α value of Ni_3Al is found to show an increase. This increase could be attributed to larger number of vacancies at off-stoichiometric compositions.

The data obtained on the coefficients of thermal expansion from room temperature to 1000 °C of Ni_3Al alloys containing third elements is shown graphically in Fig. 2. It is observed that the value of α of each alloy varies linearly with temperature. The discussion of these results will be limited to the room temperature values of α, since the effect of third elements on high temperature values is not systematic and not clearly understood at this stage. The room temperature values of the coefficient of thermal expansion of Ni_3Al alloys are given in Table 1.

Boron additions decrease the α value of Ni_3Al alloys except for the alloys of 0.20 and 1.76 at.% B. The higher values in these two alloys may be due to the lower composition of Al, because the decrease in Al content in Ni_3Al phase causes an increase in α. Since the alloy containing 1.76 at.% B is a two-phase alloy, the second phase also may increase the α value by dissolving into the matrix phase.

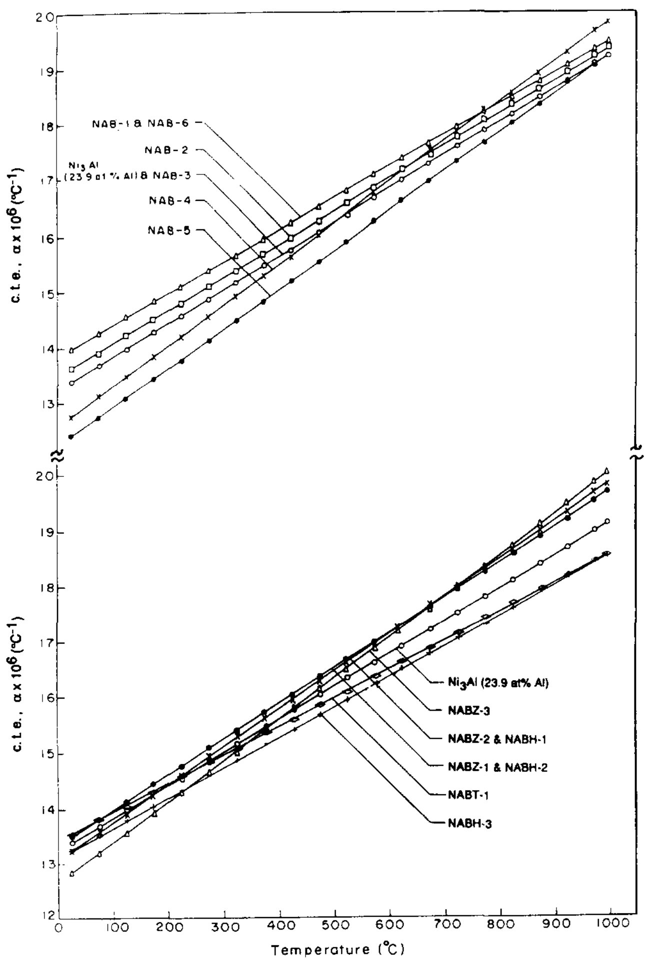

Fig. 2. Temperature dependence of the coefficient of thermal expansion of Ni_3Al alloys containing third elements.

The addition of Hf and Zr decreases the α value of Ni_3Al while Ti addition increases it. A similar behaviour in α value with the addition of Zr was observed by Arbuzov and Zelenkov [3]. They have studied the effect of Ta, Zr, V, Mn and Ti on the thermal expansion of Ni_3Al and concluded that the variation in the coefficient of thermal expansion of alloyed Ni_3Al depends on the α value of the alloying element. In the present investigation also, B and Zr, which have lower values of α, decrease the coefficient of thermal expansion of Ni_3Al whereas Hf and Ti do not alter it significantly. The heavy elements Ta, W and Re [9] and Fe [6] also reduce the thermal expansion of Ni_3Al. From these observations, one can infer that the elements which have lower values of α and the elements which have higher melting points can reduce the coefficient of thermal expansion of Ni_3Al at room temperature. However, the reduction in α of Ni_3Al with these additions is not found to be very high.

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