HIGH-TEMPERATURE FRACTURE BEHAVIOUR OF SOME Ni_3Al ALUMINIDES

M.T.Jovanović*, Ž.Bogdanov* and Dj.Drobnjak**

The 25 to 800°C fracture behaviour of a coarse grained (500-800 μm) Ni_3Al-Ti-B aluminide, additionally alloyed with either iron or cobalt, has been studied by means of scanning electron microscopy and related to its compression strength and ductility. The temperature dependence of strength and ductility is characterized by the appearance of a maximum and minimum at around 700°C and 550-700°C (depending on composition), respectively. The ductility minimum coincides with a pronounced tendency towards intergranular brittle fracture, while the overall ductility increases with increasing the amount of transgranular fracture which is promoted by addition of iron and cobalt. The effect of cobalt is particularly pronounced.

INTRODUCTION

Recently, the nickel aluminide Ni_3Al has drawn considerable attention due to attractive properties for structural applications at elevated temperatures. Ni_3Al is an intermetallic compound having the $L1_2$ ordered crystal structure. The melting point of Ni_3Al is 1290°C. Unlike conventional metallic alloys, the yield stress of Ni_3Al increases with increasing temperature (1,2). It tends to form adherent oxide films that protect the base material from excessive oxidation and corrosion (3). In addition, the density of Ni_3Al is lower than that of commercial superalloys by about 10%. The major difficulty with Ni_3Al for engineering use was extremely low ductility and brittle intergranular fracture at ambient temperatures (4, 5). Recent efforts, however, have alleviated the grain boundary brittleness by microalloying with boron (6). Alloys with substoichiometric aluminium level (24 at.%) and containing boron up to 0.1 wt.% (0.5 at.% B) exhibit room temperature ductility of up to 50% (5). These unique properties have brought Ni_3Al aluminides very close to commercial application.

* Department of Materials Science, The "Boris Kidrič" Institute of Nuclear Sciences, 11001 Belgrade, Yugoslavia.
** Department of Physical Metallurgy, Faculty of Technology and Metallurgy, University of Belgrade, 11000 Belgrade, Yugoslavia.

The principal objective of this paper was to investigate the effect of iron and cobalt additions on the high-temperature compression properties and fracture behaviour. Macroalloying can be used to increase the high-temperature strength (7). Solid solution iron additions (up to 16 wt.%) to Ni_3Al have been shown to increase the high-temperature yield stress (7). Sufficient iron additions to Ni_3Al (without boron) resulted in partial transgranular fracture instead of complete intergranular fracture and an increase in ductility during temperature bend tests, while specimens with cobalt additions showed typical intergranular fracture (8). However, no information is available on the effect of cobalt on the high-temperature properties of Ni_3Al.

EXPERIMENTAL

A boron doped Ni_3Al base alloy having a nominal composition of Ni-12wt.%Al-1.5wt.%Ti-0.16wt.%B, was additionally alloyed either with 6wt.%Fe or 7wt.%Co.

Melting was performed in Al_2O_3 crucible, while pouring has been done in a preheated ceramic mould. 100 grams cylindrical ingots were homogenized for 4 hours at 1000°C in argon atmosphere.

Compression properties were determined from 25 to 800°C in vacuum (10^{-1}Pa). Compression tests were performed on cylindrical specimens (approximately 6 mm in diameter and 12 mm in length) at a crosshead speed of $1.3 \times 10^{-3} s^{-1}$. The fractured specimens were examined using scanning electron microscope (SEM).

RESULTS AND DISCUSSION

Microstructure

A very coarse-grained structure (500-800 µm) was obtained as a result of casting in a preheated mould. While Ni_3Al-Ti-B base aluminide and that alloyed with cobalt exhibit single-phase structure, second phase is clearly observed in aluminide with iron. Macroalloying of Ni_3Al (without boron) with at least 6 wt.%Fe is reported to correspond to the formation of a second disordered phase (9). The present results appear to be in agreement with this finding. While substitutional solid solution strengthening of polycrystalline Ni_3Al by iron has been demonstrated previously (9), the role of a second phase observed in this work is yet to be determined.

Compression Strength and Ductility

The effect of temperature on the yield compression stress and ductility is shown in Figures 1(a) and 1(b), respectively. All aluminides show a positive yield stress temperature dependence, with a maximum at around 700°C. With increasing temperature ductility decreases up to 500-700°C (depending on chemical composition), then rises again. The addition of cobalt increases ductility and does not affect the yield stress. The addition of iron increases both yield stress (significantly) and ductility (slightly).

Fracture Behaviour

The 25 to 500°C fracture behaviour of low strength and low ductility (relative to the other two aluminides tested in this work) Ni_3Al-Ti-B aluminide is characterized by a mixture of quasi-cleavage transgranular fracture (denoted by TQC in Fig. 2a,b) and intergranular brittle fracture (IB in Fig. 2a). The specimen tested at 600°C is characterized by the presence of a predominantly intergranular brittle fracture (IB in Fig. 2c), with some faceted transgranular fracture. This latter develops at higher temperature (800°C) into a blocky, stepped fracture with well defined factes (Fig. 2d), possibly corresponding to crystallographic planes (to be refered to as transgranular crystallographic fracture, TC). The crystallographic facets observed in this work seems to correspond to the (111) facets, which are shown to be dominant at the fracture surface of some aluminides tested below the peak-stress temperature, T_p (10,11). According to (11,12) the (111) slip cracking is not to be confused with the (100) cleavage cracking (12), since the former takes place along the operative (111) slip planes. However, if the facets observed in this work above T_p, i.e. the temperature at which the (111) slip is replaced by (100) slip (12), are truly the (111) facets, then it seems reasonable to assume that, since slip along (111) planes is restricted, cleavage may play a role in (111) cracking above T_p. Alternatively, if these facets are the (100) planes, then cracking along (100) slip planes above T_p may be equivalent to (111) slip cracking at temperatures below T_p. Irrespective of the real mechanism the fact remains that operative mode of fracture not only recovers ductility which was lost at 600°C (Fig. 1b) due to a predominantly intergranular brittle fracture (Fig. 2c), but also increases it in respect to the 25-500°C level. However, the crystallographic nature of the fracture surface observed above T_p in this work is worthy of further studies.

The high strength medium ductility Ni_3-Al-Ti-Fe-B aluminide also exhibits a mixed mode of fracture at 25°C, except that now in addition to transgranular crystallographic (TC in Fig. 3a), quasi-cleavage transgranular (TQC in Fig. 3a) and intergranular brittle fracture (IB in Fig. 3b), a transgranular dimpled fracture is observed (TD in Fig. 3b). With increasing temperature intergranular brittle fracture increases and prevails at temperature corresponding to minimum ductility. At still higher temperature (800°C) transgranular crystallographic fracture (TC in Fig. 3c) coexists with some dimpled fracture (TD in Fig. 3c). These transgranular fractures seem to be responsible for a sharp rise in ductility at 800°C.

In the low strength high ductility Ni_3Al-Ti-Co-B aluminide, transgranular ductile fracture with shallow dimples is dominant at room temperature (TD in Fig. 4a). With increasing temperature the amount of dimples decreases, but they are still visible at 600°C. At temperature corresponding to minimum ductility (700°C) intergranular brittle fracture prevails (Fig. 4b). With further increase in temperature (800°C) the dominant mode is transgranular crystallographic fracture (TC in Fig. 4c). This brings a sharp increase in ductility in respect to its minimum level, but the room temperature ductility is not fully recovered.

CONCLUSION

The present results show that the additions of iron and cobalt to a Ni_3Al-Ti-B aluminide promote transgranular ductile fracture at the expense of intergranular brittle fracture, resulting in ductility increase. The effect of cobalt is particularly pronounced.

ABBREVIATIONS USED

IB = intergranular brittle fracture
TC = transgranular crystallographic fracture
TD = transgranular dimpled fracture
TQC= transgranular quasi-cleavage fracture

REFERENCES

(1) Thorton, P.L., Davis, R.G. and Johnson, T.L., Metall. Trans., Vol. 1, 1970, pp. 207-218.
(2) Davis, R.G. and Stoloff, N.S., Trans. TMS-AIME, Vol. 233, 1965, pp. 714-719.
(3) Aitken, E.A., "Intermetallic Compounds", Edited by J.H. Westbrook, John Wiley, New York, U.S.A., 1967.
(4) Ogura, T., Hanada, S., Matsumoto, T. and Izumi, O., Metall. Trans., Vol. 16A, 1985, pp. 441-450.
(5) Liu, C.T., White, T.L. and Horton, J.A., Acta Metall., Vol. 33., 1985, pp. 214-229.
(6) Aoki, K. and Izumi, O., Nipon Kinzoku Gokaishi, Vol. 43, 1979, pp. 1190-1195.
(7) Horton, J.A., Liu, C.T. and Santela M., Metall. Trans., Vol. 18A, 1985, pp. 1265-1277.
(8) Takasugi, T., Izumi, O. and Hasahashi, N., Acta Metall., Vol. 33, 1985, pp. 1259-1269.
(9) Dimiduk, D.M., Weddington, V.L. and Lipsitt, H.A. "High Temperature Ordered Intermetallic Alloys", Edited by N.S. Stoloff et al., Materials Research Society, Pittsburgh, U.S.A., 1987.
(10) Hanada, S., Kim, M.S., Watanabe, S. and Izumi, O., Scripta Metall., Vol. 21, 1987, pp. 277-282.
(11) Kim, M.S., Hanada, S., Watanabe, S. and Izumi, O., Trans. Japan. Inst. Metall., Vol. 29, 1988, pp. 790-797.
(12) Aoki, K. and Izumi, O., Acta Metall., Vol. 27, 1979, pp. 807-816.

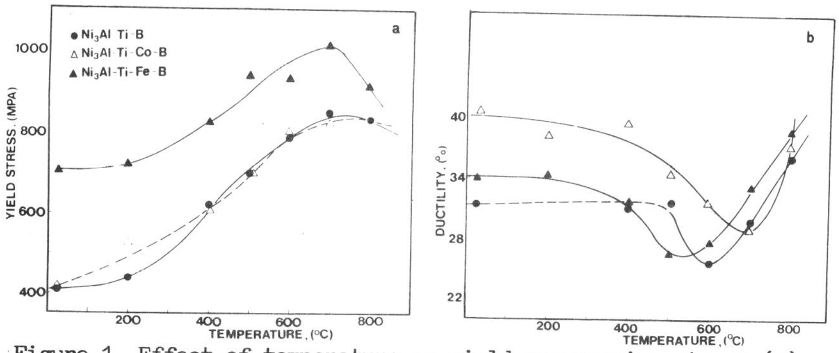

Figure 1 Effect of temperature on yield compression stress (a), and ductility (b).

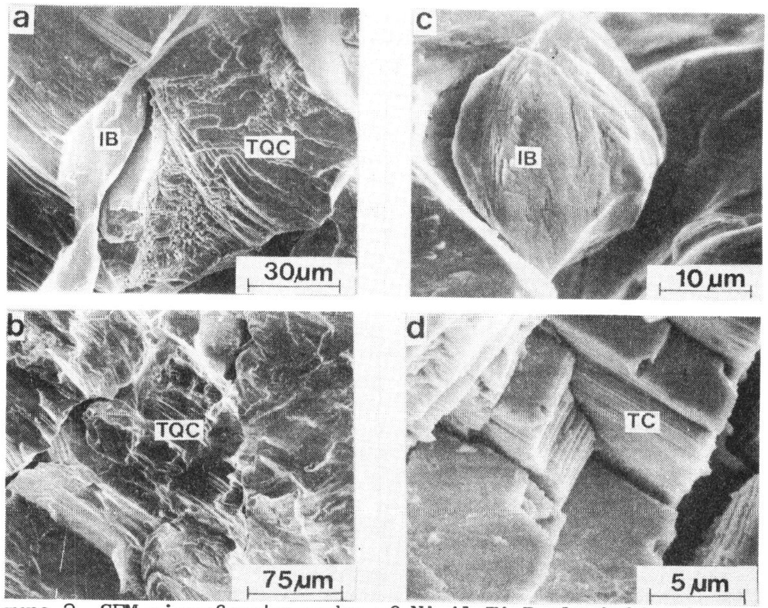

Figure 2 SEM microfractographs of Ni_3Al-Ti-B aluminide at: 25°C (a,b); 600°C (c); 800°C (d).

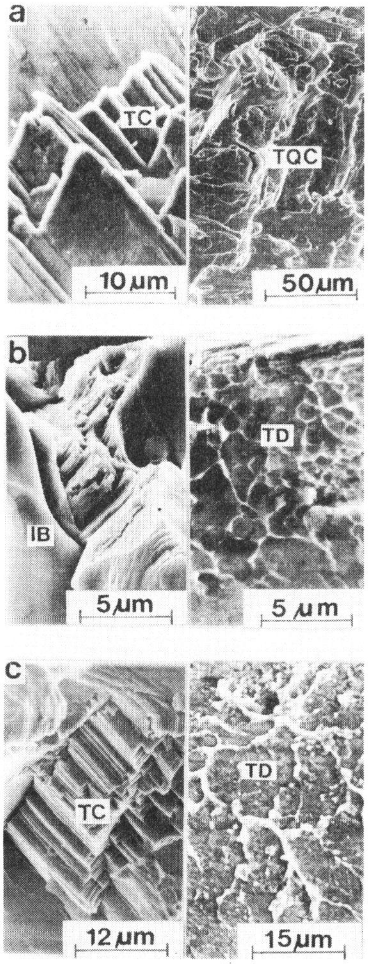

Figure 3 SEM microfractographs of Ni_3Al-Ti-Fe-B aluminide at: 25°C (a,b); 800°C (c).

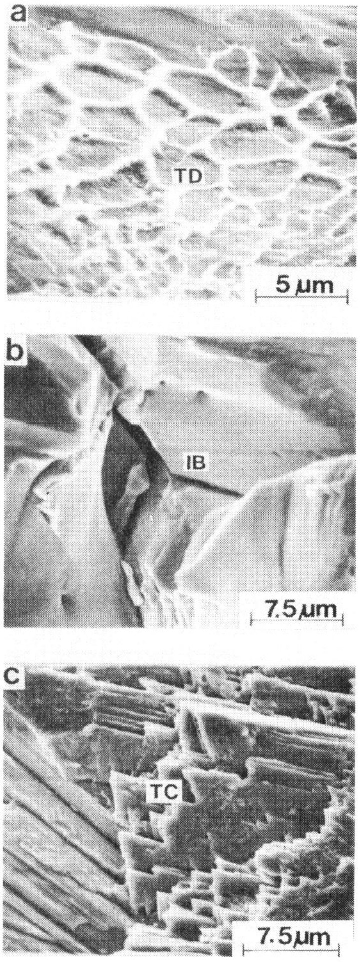

Figure 4 SEM microfractographs of Ni_3Al-Ti-Co-B aluminide at: 25°C (a); 700°C (b); 800°C (c).