RAPID PUBLICATION

Embrittlement of $\text{Ti}_3\text{Al}-10\text{Nb}-3\text{V}-1\text{Mo}$ Caused by Slight Oxidation

Yoshiyuki Saitoh and Kazuaki Mino

*Research Institute, Ishikawajima-Harima Heavy Industries Co., Ltd., Toyosu, Koto-ku,
Tokyo 135, Japan*

Residual tensile properties at room temperature of Super α_2 were examined after exposing in air. The elongation in β -solution treated materials was 2 to 2.5%. The tensile specimens were exposed at 813 or 973 K for 0.9 to 1080 ks. The elongation at room temperature has continuously decreased from 2 to 0.3% with increasing the exposure temperature and time. The ductility was almost completely recovered by mechanically removing oxidation-affected layers. The oxidation at 813 K for a half year is quite mild with a mass gain of $2 \text{ g} \cdot \text{m}^{-2}$, while the ductility of the oxidized specimen extrapolated in this work was only 0.3%. Although the detailed mechanism of embrittlement has not been clarified, it was concluded that slight oxidation has enhanced surface cracking and premature failure.

(Received December 11, 1992)

Keywords: titanium aluminide, Ti_3Al , super α_2 , embrittlement, oxidation embrittlement, residual ductility

I. Introduction

Titanium alloys are widely used in aircraft engines because of their high strength-to-density ratios. Current alloy developments have increased their maximum usable temperatures up to 873 K. The limiting temperature of these conventional alloys, however, is considered to be around 873 K not only from the high temperature strength but also from protection against the oxidizing environment. Oxidation resistant titanium aluminides offer an opportunity to further increase the service temperature of this light weight material. Super α_2 is one of the sophisticated Ti_3Al -type intermetallics, containing β stabilizing elements of Nb, V and Mo.

Super α_2 has been considered to be usable up to 923 K in air without coating⁽¹⁾⁽²⁾ and various mechanical properties have been investigated⁽³⁾⁻⁽⁵⁾. At this moment, great concerns about Ti-Al intermetallics are how to live with their low ductility and low fracture toughness at room temperature. It is for this reason that further characterizations are needed for these brittle materials. This paper reports on the effects of short-term exposure in hot air on the residual ductility of Super α_2 .

II. Experimental Procedure

Forged bars of 44 mm diameter with a composition of Ti-13.8Al-20.0Nb-2.63V-2.10Mo (mass%) were kindly supplied by Daido Steel Co. The oxygen and nitrogen contents were 0.046 mass% and 0.009 mass%, respectively. The bars were solution-heat treated at 1473 K for 1.8 ks followed by cooling in vacuum with a cooling rate

of about $0.5 \text{ K} \cdot \text{s}^{-1}$. They were subsequently stabilized at 1033 K for 65 ks and then cooled in air. These heat treatment produced a Widmanstätten structure consisting of α_2 and β . Tensile specimens of 4 mm in gauge diameter and 25 mm in gauge length were sampled from the bars. Tensile tests were done in air with a strain rate of $1.3 \times 10^{-4} \text{ s}^{-1}$.

III. Results and Discussion

Tensile specimens were exposed in air at 973 K for 360 ks. Some of them were exposed under the stress of 200 MPa to produce a plastic strain of about 0.5%. These exposed specimens were tensile-tested at room temperature. The elongations are shown in Fig. 1. The influence of thermal exposure on the yield stress and work hardening rate was not found. The virgin materials have the elongations of 2 to 2.5%, but they were severely embrittled by thermal exposure or creep. The smallest elongation in Fig. 1 is 0.3%.

Figure 2 shows how the tensile strength and elongation decreased with the oxidation temperature and time. The oxidation time was varied from 0.9 to 1080 ks at 813 K and 973 K. Here, the activation energy for oxidation of Ti_3Al ⁽⁶⁾ was used for the Q -value in the kinetic strength parameter $t \exp(-Q/RT)$. Embrittlement became severer with the increase in exposure temperature and time. The tensile strength decreased in accordance with the decrease in elongation.

The weight increase of Super α_2 by oxidation at 973 K for a half year was estimated to be about $10 \text{ g} \cdot \text{m}^{-2}$ from Ref. (7), which would be an acceptable level to be used without any protective coating. However, the elongation

Fig. 1 Effect of exposure in air at 973 K for 360 ks on tensile elongation at room temperature. Creep specimens were strained to about 0.5%.

Fig. 3 Recovery of ductility by removing oxidation-affected layers.

after this exposure was extrapolated from Fig. 2 to be 0.3% or less. The extrapolated elongation after a half year exposure at 913 K is 0.3%, while the mass gain by oxidation was estimated to be $2 \text{ g} \cdot \text{m}^{-2}$. This indicates that the loss in ductility by exposure in hot air was more serious than oxidation itself.

The ductility was almost completely restored by removing the oxidation-affected zone at the near surface as shown in Fig. 3. First, the sample was slightly oxidized at 973 K for 0.9 ks, producing an oxide layer of less than $1 \mu\text{m}$ in thickness. Its elongation at room temperature decreased from 2 to 0.6%. But, after removing the surface layer, the ductility recovered to the original level. The embrittlement by creep also disappeared after refreshing the surface by grinding. These results indicate that the embrittlement is related to the oxidized surface layer.

Many surface cracks were observed in the preoxidized and tensile-tested specimen as shown in Fig. 4. Much less surface cracking was observed in the virgin and refreshed materials. Cross-sectional observations revealed that most of the subcracks have penetrated only to a depth of 20 to $30 \mu\text{m}$. These facts indicate that the near surface area has become prone to cracking by exposure in hot air.

Embrittlement by oxygen penetrations is known to become harmful to most titanium alloys. In order to avoid damages due to alpha case, heat treatment atmosphere is controlled and skins of products are often removed after heat treatment. But, in the present aluminide, extremely slight modification of the surface layers has seriously decreased the ductility. The present test temperature of 813 K, at which even a conventional titanium alloy is used without coating, will be too low to oxidize Super α_2 beyond the detection limit of ordinary analyzers.

This kind of embrittlement by slight exposure in hot air is not restricted to Super α_2 , but also appeared in the gamma-type aluminide, Ti-47 mol%Al⁽⁸⁾. The four-point bending fracture strain at room temperature decreased from 1 to 0.3% by increasing the exposure tem-

Fig. 2 Decrease in tensile strength and elongation at room temperature as a function of the exposure time-temperature parameter, $t \exp(-Q/RT)$. Q is the activation energy, 262 kJ/mol.

Fig. 4 Severe surface cracking in the specimen oxidized at 973 K for 0.9 ks and subsequently tensile-tested at room temperature. (a) surface, SEM, (b) cross-section.

perature to 973 K in air. Here, the exposure time was fixed to 1.8 ks. The similar results have recently been reported using Ti-48Al-1V-0.2C (mol%)⁽⁹⁾. The embrittlement was indebted to a brittle surface layer with a cubic crystal structure and Ti:Al ratio of 2:1 rather than an oxide layer. Although the detailed mechanism of embrittlement has not been clarified in the present work, it is proposed that the slight oxidation has enhanced the surface cracking and premature failure of Super α_2 .

IV. Conclusion

Slight oxidation was shown to enhance the surface cracking and decrease the room temperature ductility of Super α_2 , originally having 2 to 2.5% in elongation, to 0.3% or less.

REFERENCES

- (1) R. G. Rowe: *High Temperature Aluminides and Intermetallics*, ed. by S. H. Whang, C. T. Liu, D. P. Pope and J. O. Stiegler, Materials Research Society, Pennsylvania, (1990), p. 373.
- (2) Y.-W. Kim and F. H. Froes: *ibid*, p. 465.
- (3) W. Cho, A. W. Thompson and J. C. Williams: *Metall. Trans.*, **21A** (1990), 641.
- (4) D. P. Deluca, R. A. Cowles, F. K. Haake and K. P. Holland: WRDC-TR-89-4136, Wright Research & Development Center, (1989).
- (5) M. J. Blackburn and M. P. Smith: WRDC-TR-89-4095, Wright Research & Development Center, (1989).
- (6) G. Welsch and A. I. Kahveci: *Oxidation of High Temperature Intermetallics*, ed. T. Grobstein and J. Daychak, TMS, Warrendale, Pennsylvania, (1989), p. 207.
- (7) K. E. Wiedeman and S. N. Sankaran: *ibid*, p. 195.
- (8) K. Mino and Y. Saitoh: unpublished work.
- (9) W. E. Dowling, Jr. and W. T. Donlon: *Scripta Metall.*, **27** (1992), 1663.