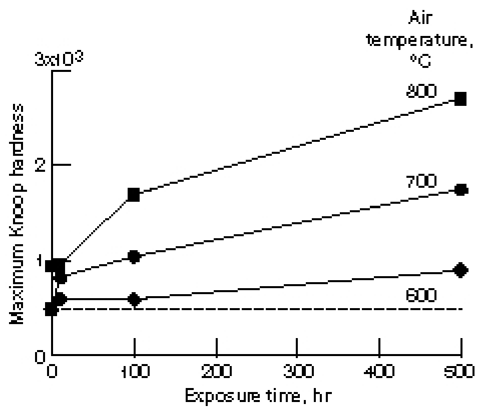
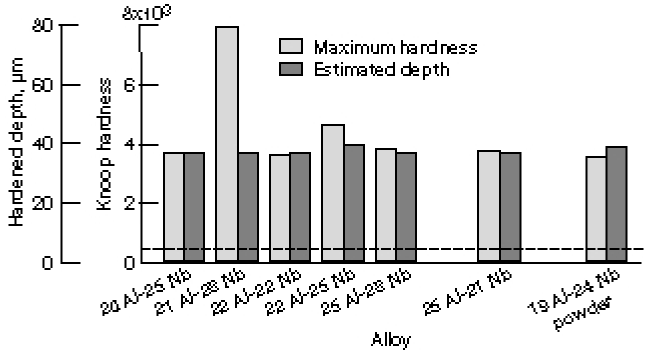
Environmental Studies on Titanium Aluminide Alloys

Titanium aluminides are attractive alternatives to superalloys in moderate temperature applications (600 to 850 °C) by virtue of their high strength-to-density ratio (high specific strength). These alloys are also more ductile than competing intermetallic systems. However, most Ti-based alloys tend to degrade through interstitial embrittlement and rapid oxidation during exposure to elevated temperatures. Therefore, their environmental behavior must be thoroughly investigated before they can be developed further. The goals of titanium aluminide environmental studies at the NASA Lewis Research Center are twofold: characterize the degradation mechanisms for advanced structural alloys and determine what means are available to minimize degradation. The studies to date have covered the α_2 (Ti_3Al), orthorhombic (Ti_2AlNb), and γ(TiAl) classes of alloys.



Near surface hardening of O-Ti as a function of air exposure duration at 600, 700, and 800 °C. The horizontal dashed line indicates the baseline hardness of the unexposed material.

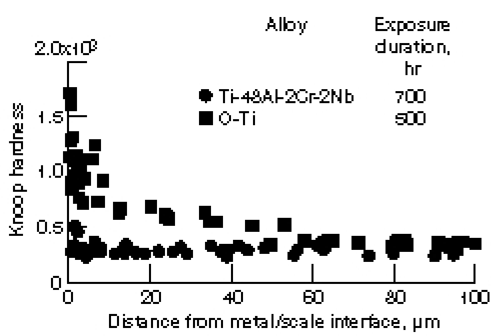
The α_2 and orthorhombic (abbreviated here as O-Ti) alloys had high rates of oxidation at 800 °C, but the limiting environmental factor for both appears to be interstitial embrittlement during air exposure (refs. 1 and 2). Embrittlement, as measured by microhardness profiling, was significant for both the α_2 and O-Ti classes of alloys after exposure to 800 °C air for only 1 hr (see the graph above) and was measurable after 100 hr at 600 °C. In related studies at NASA Lewis, this level of embrittlement dramatically reduced the fatigue lives of α_2 and O-Ti alloys (refs. 3 and 4). Examination of oxidation and embrittlement behavior as a function of composition showed that alloying was effective in reducing oxidation (as in the following graph), but was not effective in preventing or reducing embrittlement in any of 11 different O-Ti alloys examined (provided by the Materials Directorate at Wright Laboratory).



Depth of embrittlement after 500-hr exposure to 800 °C air does not correlate to O-Ti composition. The horizontal dashed line indicates the baseline hardness of the unexposed material.

Coatings have been examined as a means to retard embrittlement in α_2 alloys and are under investigation for O-Ti alloys. For α_2 alloys, the coatings examined include those in the MCrAlY family, mixed ceramic-metallic coatings, and graded coatings. Silicide coatings have been examined for O-Ti alloys. Although all these coatings provide oxidation resistance and resistance to oxygen ingress, fatigue testing of coated coupons showed that all coatings induced a fatigue life debit that was more severe than the environmental embrittlement effect that the coating was supposed to prevent. This result is in general agreement with previous coating efforts on Ti-based alloys.

Three different γ alloys were also evaluated in terms of their oxidation and embrittlement behavior: Ti-48Al-2Cr-2Nb (GE alloy, 48-2-2), Ti-46.5Al-3Nb-2Cr-0.2W (Universal Energy Systems alloy, K-5), and Ti-46Al-5Nb-1W (Allison alloy, Alloy 7). The 48-2-2 alloy had marginally acceptable oxidation kinetics at 800 °C, whereas both K-5 and Alloy 7 had acceptable oxidation rates to beyond 1000 hr at 800 °C.



γ TiAl has no detectable hardening after long-term exposure to 800 °C air, in contrast to O-Ti alloys that show extensive hardening under the same conditions.

Microhardness profiling detected no evidence of embrittlement for any of the three γ alloys after a 1000-hr exposure to air at 800 °C. This is in stark contrast to the embrittlement behavior noted earlier for α_2 and O-Ti alloys (as shown in the last graph). However, data from other labs suggest that γ alloys do show a decrease in fatigue life when 600 °C vacuum and 600 °C air mechanical fatigue results are compared (ref. 5). Since the fatigue debit is relatively minor and the initial intent is to use these alloys in low-strain conditions, coatings may help extend the life of γ alloy components. A highly oxidation-resistant Ti-Al-Cr coating alloy, which combines excellent γ substrate compatibility with toughness, has been developed at NASA Lewis (ref. 6). This alloy is being evaluated as an oxidation and embrittlement resistant coating designed to enhance the life of structural γ-alloys.

References

1. Brindley, W.J.; Smialek, J.L.; and Gedwill, M.A.: Oxidation Resistant Coatings for Ti_3Al+Nb and SiC/Ti_3Al+Nb. HITEMP Review 1992, NASA CP-10104, Vol. II, 1992, pp. 41-1 to 41-15.

2. Brindley, W.J., et al.: Oxidation and Embrittlement of Orthorhombic-Titanium Alloys. HITEMP Review 1994, NASA CP-10146, Vol. II, 1994, pp. 44-1 to 44-11.

   Gabb, T.P.; and Gayda, J.: Fatigue Behavior of a Unidirectionally Reinforced Orthorhombic Matrix Composite. HITEMP Review 1993, NASA CP-19117, Vol. II, 1993, pp. 33-1 to 33-10.

3. Brindley, P.K.; and Bartolotta, P.A.: Isothermal Fatigue Behavior of SiC/Ti-24Al-11Nb. HITEMP Review 1991, NASA CP-10082, 1991, pp. 46-1 to 46-13.

4. Larsen, J.M., et al.: Reliability Issues Affecting the Implementation of Gamma Titanium Aluminides. Turbine Engine Applications. Institute of Materials 1996, Eighth World Conference on Titanium. P.A. Blenkinson, et al., eds., vol. 620, pt. 1, Institute of Materials, London, 1996, pp. 113-120.

5. Brady, M.P.; Smialek, J.L.; and Brindley, W.J.: Oxidation-Resistant Coating Alloy for Gamma Titanium Aluminides. Research & Technology 1996. NASA TM-107350, 1997, pp. 66. Available WWW: http://www.grc.nasa.gov/WWW/RT1996/5000/5160ba.htm

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