Effect of strain rate on cyclic deformation behavior of a beta phase containing TiAl alloy at elevated temperature

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Abstract. A beta phase containing titanium aluminum compound was prepared. Isothermal Fatigue(IF) were subjected at 650 ℃ at three strain rates, such as 6.67×10-3 s-1, 6.67×10-4 s-1, 6.67×10-5 s-1 to determine the effect of strain rate on cyclic stress-strain response (CSSR) of TiAl alloy during IF tests. The curves of cyclic stress-strain response were also discussed. The results show that strain rates have an apparent effect on CSSR of TiAl alloy during IF tests.

Introduction

Gamma titanium aluminum compounds are currently receiving much attention as candidates of high temperature structural application in aerospace and automobile industries because of weight saving in combination with excellent mechanical properties such as large stiffness, high strength and excellent creep and oxidation resistance at elevated temperature [1-3].

In the last decades, considerable efforts on TiAl alloys, such as alloying [4,5], heat treatment [4], thermo-mechanical treatment [6,7], have been devoted to improving their low room temperature ductility and poor fracture toughness which will be a serious handicap for their actual applications. Recently, βphase containing TiAl alloys have been developed widely, due to good hot deformability. For example, Kim et al. [6], put forward a new concept of beta-TiAl alloys, which existed within a broad composition range of Ti-(40-45)Al-(2-8)Nb-(1-8)(Cr, Mn, V, Mo)-(0-0.5)(B, C) (in at.%).

Its cyclic deformation behaviors of as casted β phase containing Ti-44Al-2Cr- 2Nb-0.15B alloy during isothermal fatigue (IF) tests under different strain rate were explored in the present work thus its deformation behaviors, fatigue endurance and resistance to oxidation at elevated temperature can be acquired for conducting its applications for aerospace and automobile industries as important high temperature structural.

Experimental

The chemical composition of nominal Ti-44Al-2Cr-2Nb-0.15B alloy is 43.66 % Al, 2.11 % Cr, 2.09 % Nb, 0.15 % B and balance Ti (atomic percentage). Ingots were prepared by centrifugal casting after consumable electrode melting, hot isostatically pressed (HIPed) at 1280 ℃ and 200 MPa for 4 hrs followed by heat treatment at 900 ℃ for 4 hrs. As can be seen in Fig.1, microstructure of this alloy consists of α_2/γ colonies and some borides distributed along grain boundaries and α_2/γ interfaces.

IF tests were carried out on a servo-hydraulic testing system MTS810 under mechanical strain control using a triangle wave-shape on smooth cylindrical specimens with a gauge length of 18 mm and a diameter of 7 mm. The samples were heated with a high frequency induction heater. Heating rate was 5 K/s and axial temperature deviations within the gauge length were below ±5 ℃.

Temperature was measured with a thermocouple fixed on specimen by a spot-welder. All tests were performed in laboratory air. The test temperature of 650℃ was used during IF tests. Strain rate such as 6.67×10^{-3} s^{-1}, 6.67×10^{-4} s^{-1}, 6.67×10^{-5} s^{-1} was applied. Mechanical strain amplitude were confined to 0.3 %.

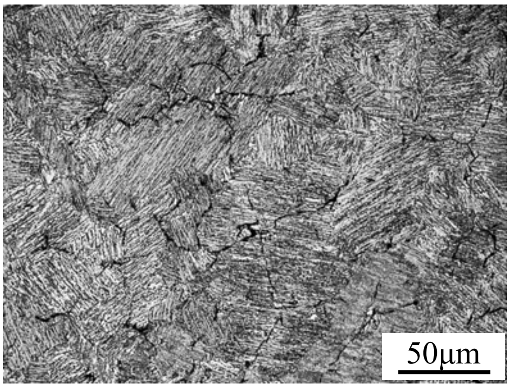

Fig.1 Microstructure of near gamma-TiAl before IF tests

The mechanical strain ε_{mech} was calculated from the total measured strain ε_{total} by subtraction of the thermal expansion strain ε_{ther}, such as Formula 1. For an exact strain measurement, the testing system has to be in thermal steady state. Therefore, four initial cycles at zero stress were carried out before determination of thermal expansion, thermal expansion strain compensation and testing.

$$\Delta\varepsilon_{mech} = \Delta\varepsilon_t - \Delta\varepsilon_{ther} \tag{1}$$

Subsequently two initial heating cycles were carried out on all samples before the first TMF test. In the first cycle, a stress-controlled test at zero stress was used in order to determine the thermal expansion of the samples. The second cycle was carried out in mechanical strain control with zero mechanical strain as control value (i.e. totally measured strain minus thermal strain). In this second cycle, the stress was less than 20 MPa at all points of the hysteresis loops, thus showed that the thermal expansion strain compensation was working correctly.

The microstructure details and dislocation arrangements were studied after testing by transmission electron microscopy (TEM) using a Philips CM 30. The samples were prepared by

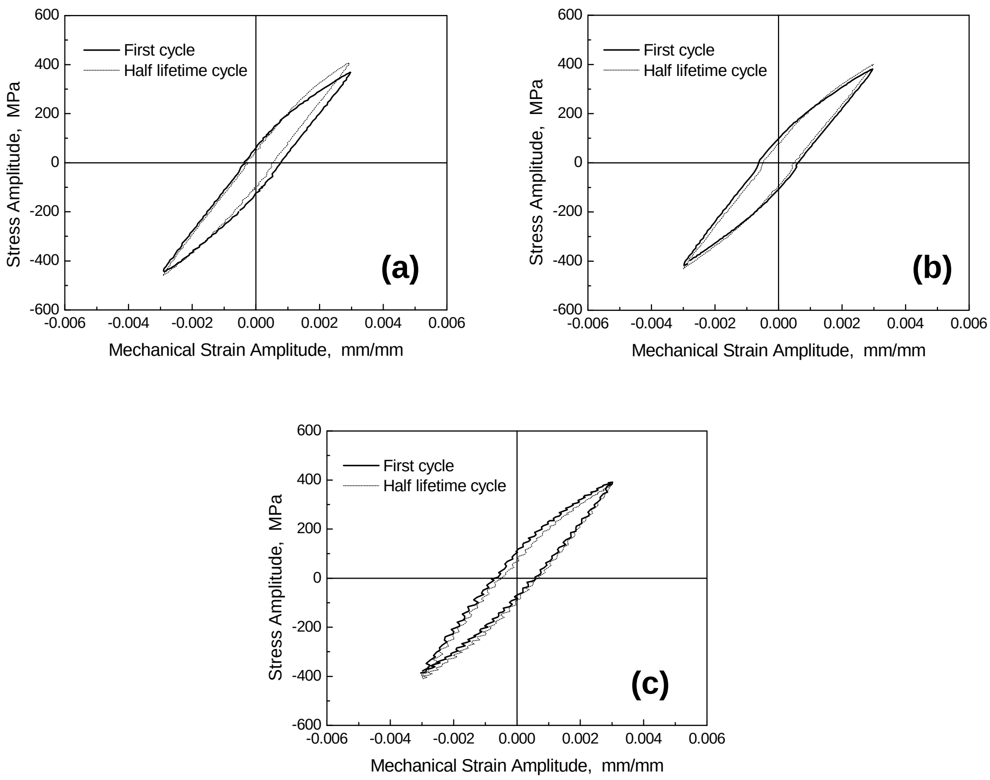

Fig. 2 Effect of strain rate on hysteresis loops of isothermal fatigue at 650°C and $\Delta\varepsilon_t/2$=0.3% (a) 6.67×10^{-3} s^{-1},(b) 6.67×10^{-4} s^{-1} and (c) 6.67×10^{-5} s^{-1}.

electrolytic double jet thinning at a temperature of -30 ℃with a methanol-butanol perchloric acid electrolyte.

Results and discussion

Hysteresis loops of isothermal fatigue have a more better symmetry than those of thermo-mechanical fatigue which were reported in author's former work [8,9]. The lower strain rate, the symmetry of hysteresis loops was better. At strain rate 6.67×10^{-3} s^{-1}, center of hysteresis loops lay nether right of the axis zero, which meant tensile peak stress larger than compressive peak stress, while cycling number came to half lifetime cycling, hardening appeared at both tensile-compressive cycling(Fig.2a). Whereas strain rate had a decuple and centuplicate drop, namely 6.67×10^{-4} s^{-1} and 6.67×10^{-5} s^{-1}respectively, hysteresis loops factually had a rather better zero symmetry(Fig.2a and Fig.2c). However they revealed some discrepancy at half lifetime cycling. When strain rate dropped to 6.67×10^{-4}, an apparent hardening occurred at both tensile-compressive cycling(Fig.2b), otherwise, strain rate decreased to 6.67×10^{-5} during isothermal fatigue, a different hardening-softening tendency generated at tensile-compressive cycling, that is to say, a slight softening took place at tensile peak stress cycling and a little hardening at compressive peak stress cycling(Fig.2c).

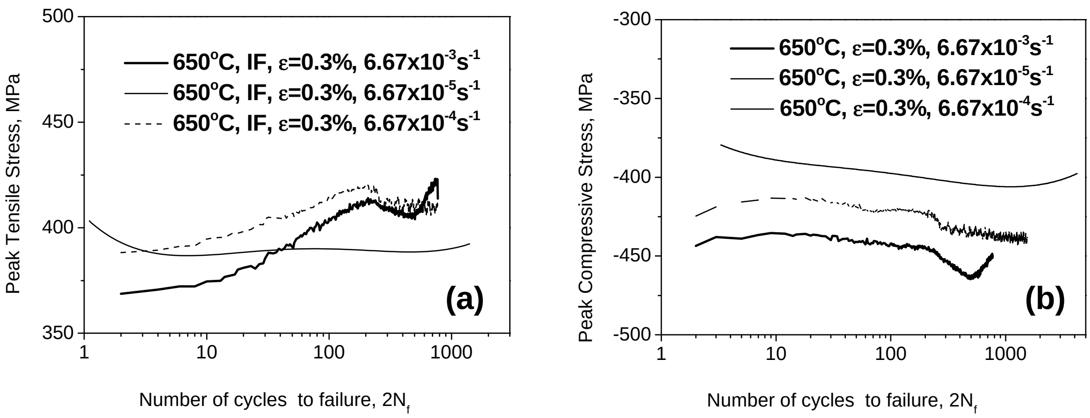

Fig.3 Cyclic stress response curves of isothermal fatigue tests at different strain rate (a) at tensile peak stress cycle and (b) at compressive peak stress cycle.

Conclusions

Cyclic stress-strain response (CSSR) of a β phase containing Ti-44Al-2Cr-2Nb-0.15B alloy during isothermal fatigue (IF) tests under different strain rate were evaluated in this paper. It was identified that strain rate played an important role on CSSR of IF tests of TiAl alloy. At lower strain rates, a slight softening appeared during tensile peak stress cycle while an apparent hardening lasted out when strain rate increased with large amplitude.

Acknowledgements

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References

[1] Kim Y W. Intermetallics. 1998; 6(7-8): 623-628.
[2] Liu C T, Kim Y W. Scripta Metallurgica et Materialia, 1992; 27(5): 599-603.
[3] Huang J S, Kim Y W. Scripta Metallurgica et Materialia, 1991; 25(8): 1901-1906.
[4] Loretto M H, Godfrey A B, Hu D, Blenkinsop P A, Jones I P, Cheng T T. Intermetallics 1998; 6:

663-6.
[5] Kampe S L, Sadler P, Christodoulou L. Metall Mater Trans A 1994; 25: 2181-797.
[6] Shih Donald S, Kim Y W. In: Ninomi M, Akiyama S, Ikeda M, editors. Ti-2007 Science and Engineering. Kyoto, Japan: The Japan Institute of Metals, 2007：1021-4.
[7] Bartels Arno, Kestler Heinrich, Clemens Helmut. Mater Sci Eng A 2002;329-331: 153-62.
[8] Xiang Hongfu, Dai Anlun, Li Hui, Li Shouxin, Cui Yuyou, Yang Rui. Adv Mater Res. 2012; 468-471: 2193-00.
[9] Xiang Hongfu, Dai Anlun, Wang Jiheng, Li Hui, Yang Rui. Trans Nonfer Met Soc China. 2010; 20: 2174-80.