# IN-SITU OBSERVATION OF FATIGUE CRACK GROWTH IN CENTRIFUGAL SPRAY DEPOSITION (CSD) Ti-48Al-2Mn-2Nb ALLOY[①]

Song Xiping, Cai Heping, Chen Wenzhe† and Gu Haicheng
*State Key Laboratory for Mechanical Behavior of Materials, Xi'an Jiaotong University, Xi'an 710049, P. R. China*
† *Department of Materials, Fuzhou University, Fuzhou 350002, P. R. China*

**ABSTRACT** In-situ observation was carried out on fatigue crack growth in centrifugal spray deposition (CSD) Ti-48Al-2Mn-2Nb alloy with self-made SEM fatigue loading stage. The results show that the fatigue crack propagates with increase of cyclic stress level, while the cyclic number has a little effect on it. The lamellar structure has a great influence on fatigue crack propagation by torturing the crack growth path and changing the crack propagation direction. TEM observation shows that deformation twinning is sensitive to the cyclic stress level, and at the high cyclic stress level a large amount of deformation twins can be found, indicating that cyclic twinning becomes the dominant deformation mode at this stress level.

**Key words** centrifugal spray deposition (CSD) Ti-48Al-2Mn-2Nb alloy fatigue crack

## 1 INTRODUCTION

TiAl intermetallic compounds are currently seen as candidate materials for high temperature structural application in aeronautical industry due to their low density, superior high temperature strength and excellent creep resistance[1, 2]. With development and improvement of these alloys, the requirement for some gas-turbine and automobile engine components used at high temperature has been met by the second-generation gamma alloys, Ti-48Al-2Mn-2Nb and derivatives, thus, much attention has been focused on these alloys[3]. The fatigue behaviour on the rule of fatigue crack propagation was studied[4-6], but the information on cyclic deformation mechanism, especially at room temperature, is very limited. Thus, in this paper, the behaviour of surface fatigue crack propagation and micro-mechanism of cyclic deformation in Ti-48Al-2Mn-2Nb alloy produced by CSD were investigated at ambient temperature and some interesting results were obtained.

## 2 EXPERIMENTAL PROCEDURES

The Ti-48Al-2Mn-2Nb alloy was procured from the Interdisciplinary Research Centre in Materials for High Performance Applications, University of Birmingham, UK. CSD, e.g. the ingots with the nominal composition and very little impurity are melted in a Retech furnace induction heated and the melt is bottom poured through a graphite nozzle into the solidification chamber. At the position 250 mm below the graphite nozzle, a rapidly rotating (3 000 r/min) water-cooled disc atomizes the falling stream and the resultant spray impacts onto the inside wall of the chamber to form a ring shaped product with the sizes of 400 mm in diameter, 150 mm in axial height and ~ 10 mm in thickness. The original specimens for test were cut from the ring using an electric discharge machine (EDM) to the dimensions of 4 mm × 8 mm × 40 mm with single-side notch and were precracked in uniaxial

① Received Nov. 27, 1997; accepted Apr. 27, 1998

cyclic compression on an AMSLER HFP5100 machine. Then these specimens were sectioned to in-situ fatigue specimens shown in Fig. 1 and mechanically polished and etched (Kroll's II reagent) for SEM observation.

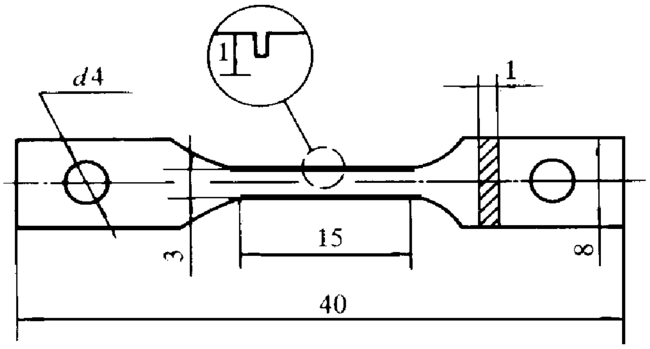


**Fig. 1** Dimensions of fatigue specimens for in-situ observation in SEM

The in-situ cyclic deformation was carried out on the fatigue loading stage within the chamber of JSM-35C which can control the cyclic stress and cyclic number. The cyclic loading mode was tension-tension with the stress ratio $R = 0.1$, frequency $f = 0.25\sim 1.00$ Hz. The increasing range of cyclic stress was 10 N when the cyclic numbers got to $1\times 10^3$ cycles. Under a certain cyclic stress level surface observation of fatigue crack propagation was taken periodically at preplanned cyclic numbers. Thin foils for TEM observation were sectioned from the in-situ specimens in different cyclic stress amplitude and prepared by twin jet electropolishing with solution of methanol∶glycol∶perchloric acid = 200∶10∶15. TEM observation was accomplished in JEM-200 CX operating at 200 kV.

## 3 RESULTS AND DISCUSSION

The SEM microstructures of Ti-48Al-2Mn-2Nb alloy is shown in Fig. 2 (a), (b). It can be seen that the lamellar colonies with irregular boundary was produced and its size was found to be an average of 200 μm in diameter. Inside a lamellar colony, the lamellar laths aligned themselves in the same direction in brighter and darker contrast. Analysis by TEM indicated that

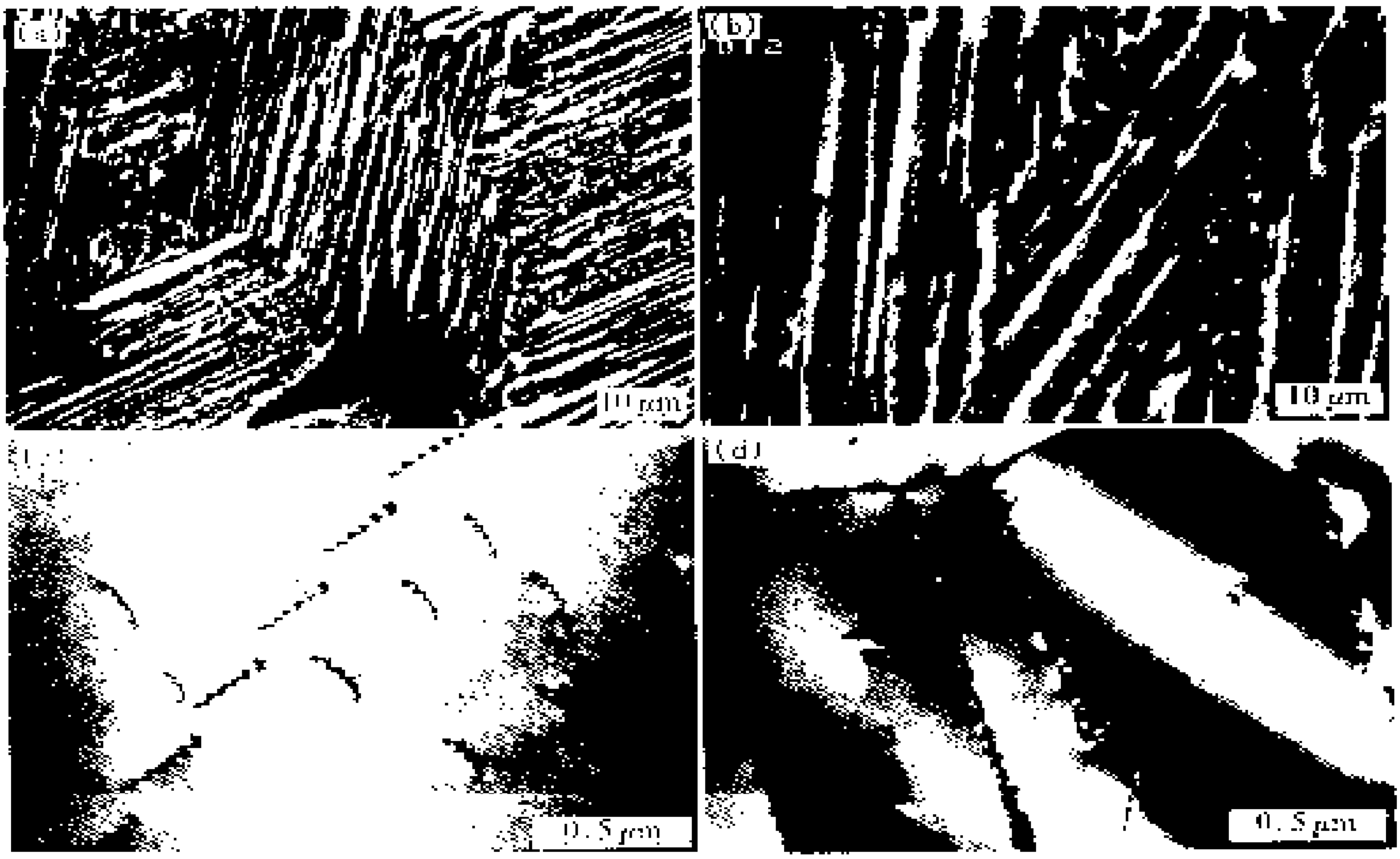


**Fig. 2** Microstructures of Ti-48Al-2Mn-2Nb alloy
(a), (b) —SEM images; (c), (d) —TEM images

these laths had the same $L1_0$ structure, and the dislocations of low density was found to trend to array themselves parallel to the lath boundary as shown in Fig. 2 (c) and (d). This may be related to the $\alpha \rightarrow \gamma$ massive transformation during this fast solidification[7].

The results of in-situ observation showed that when the maximum stress intensity $K_{max}$= 4.3~ 9.1 MPa•$m^{1/2}$, no obvious variation was found at the tip of fatigue cracks. When the maximum stress intensity $K_{max}$ = 11.1 MPa•$m^{1/2}$, the fatigue cracks became blund and began to form micro-crack in the crack tip, as shown in Fig. 3. When $K_{max}$= 13.0 MPa•$m^{1/2}$, the specimen was broken within one cycle. This indicates that the fatigue behaviour of this alloy is similar to that of brittle materials[8], e.g. the fatigue damage is accumulated not only by cyclic plastic deformation, but also by the formation of micro-cracks. When the cyclic loading exceeds a certain critical stress value, the microcracks will propagate quickly and cause specimens to break unexpectedly. During fatigue processing the cyclic number had a little effect on the crack propagation. This indicates that the fatigue damage is more sensitive to the cyclic stress than that to the cyclic number.


**Fig. 3** Behavior of fatigue crack propagation by in-situ observation ($K_{max}$= 11.1 MPa$m^{1/2}$, $N$= 512)

The crack propagation was also affected by the lamellar colonies and laths. When the crack propagated perpendicular to the lamellar laths, crack path was much more tortuous, and when the crack was hindered by a lamellar colony, its propagative direction was changed to along the boundary between these two colonies, as shown in Fig. 4 (a). This may be related to the anisotropy of lamellar structure. Meanwhile bifurcated micro-crack formed intermittently and could be connected with increasing of cyclic stress, as shown in Fig. 4, implying that the crack propagation was uncontinuous.

TEM observation showed that with increasing of cyclic stress amplitude, the number of de-

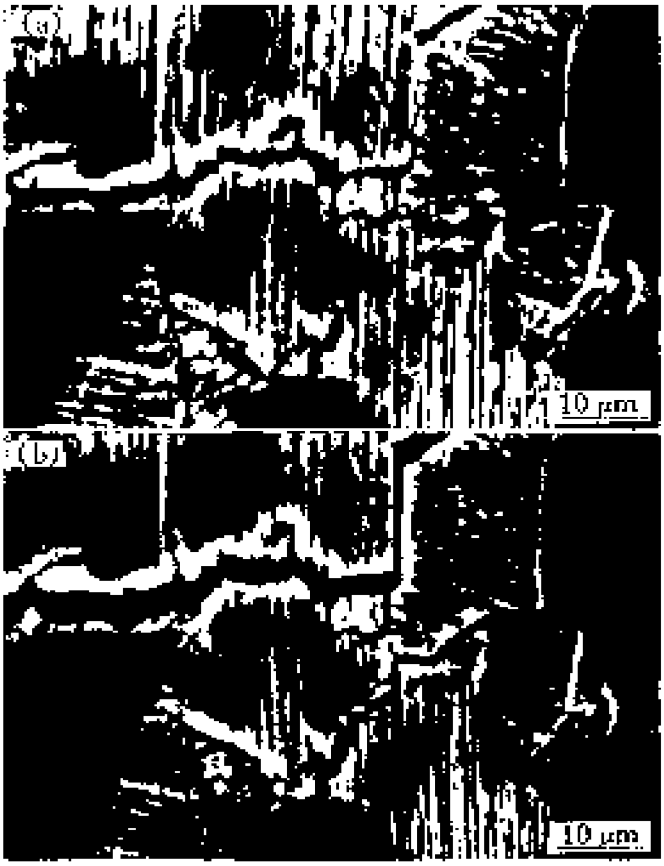


**Fig. 4** Effect of lamellar structure on fatigue crack propagative path
(a) —$K_{max}$= 10.6 MPa $m^{1/2}$, $N$= 112;
(b) —$K_{max}$= 12.1 MPa $m^{1/2}$, $N$= 312

formation twins increased more obviously compared with that of dislocations as shown in Fig. 5. It is consistent with experimental result made by Soboyejo[9] that the crack tip can induce the twinning more easily than inducing slip under cyclic deformation at room temperature.

Theoretically, the deformation mode in TiAl compounds includes 1/2⟨110] unit dislocation, ⟨011] and 1/2⟨112] superlattice dislocation and twinning. At room temperature, the superlattice dislocation might be dissociated to a Kear-Wilsdorf lock or stacking faults and make the slip difficult, so the deformation twinning became relatively active[10]. Meanwhile, the alloying element Mn could increase deformation twinning[11], thus twinning became a more important deformation mode in this process. Since twinning was controlled by the applied stress, the number of deformation twinning would increase with increasing cyclic stress, and at high cyclic stress amplitude the twinning became the main deformation mode.

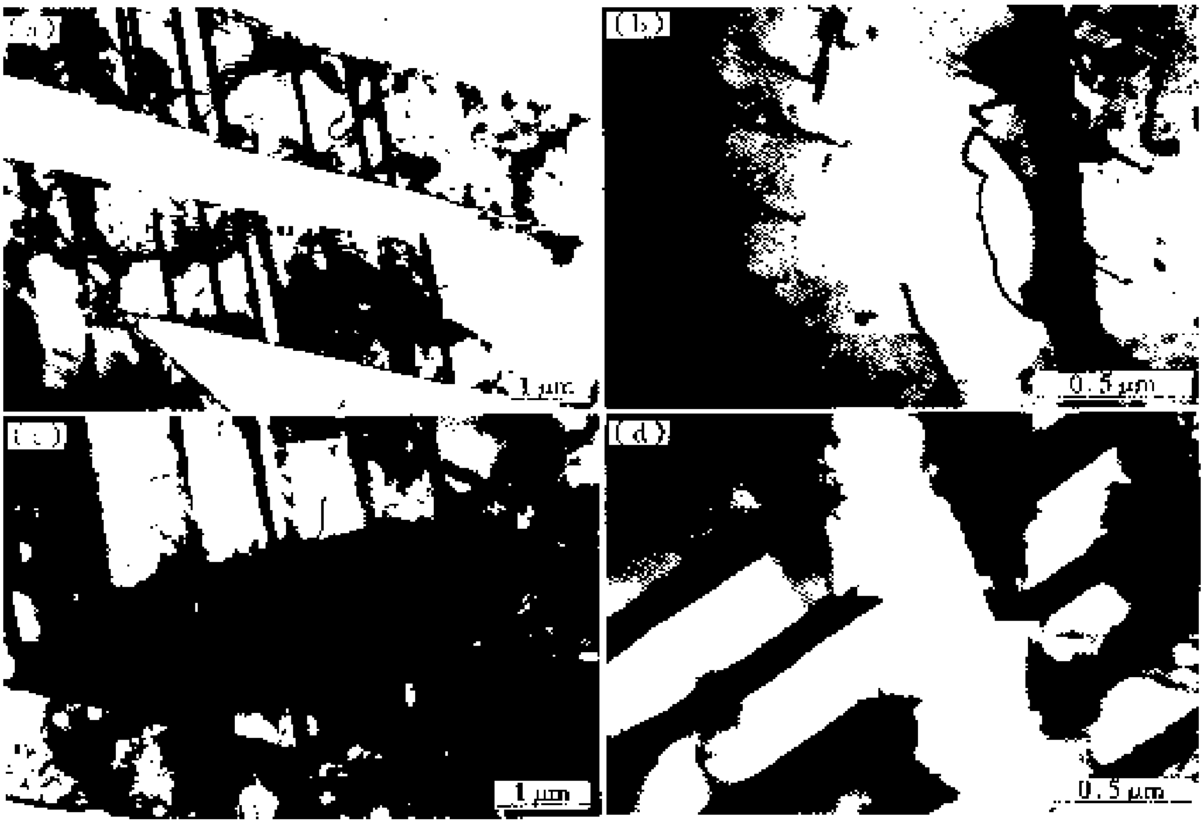


**Fig. 5** TEM images of fatigue specimens at different cyclic stress levels
(a), (b) —$K_{max}$ = 11.1 MPa·m$^{1/2}$, $N$ = 345; (c), (d) —$K_{max}$ = 12.8 MPa·m$^{1/2}$, $N$ = 112

## REFERENCES

1 Kim Y-W. JOM, 1994, 46(7): 30.
2 Yamaguchi M, Inui H, Yokoshima S *et al*. Mater Sci Eng, 1996, A213: 25.
3 Chen Wenzhe, Jacobs M H and Loretto M H. The Chinese Journal of Nonferrous Metals, (in Chinese), 1996, 6(3): 86.
4 Soboyejo W O, Deffeyes J E and Aswath P B. Mater Sci Eng, 1991, A138: 95.
5 Bowen P, Chare R A and James A W. Mater Sci Eng, 1995, A192/193: 443
6 Malakondaiah G and Nicholas T. Metall Trans, 1996, 27A: 2239.
7 Chen Weizhe, Song Xiping, Qian Kuangwu *et al*. Mater Sci Eng A, in press.
8 Suresh S. Fatigue of Materials. London: Cambridge University Press, 1991.
9 Soboyejo W O and Mercer C. Scripta Metall Mater, 1994, 30(12): 1515.
10 Christian J W and Mahajan S. Prog Mater Sci, 1995, 39: 1.
11 Hanamura T, Uemori R and Tanino M. J Mater Res, 1988, 3: 656.

**(Edited by Huang Jinsong)**