Fatigue Cracking Behavior in Aluminum 7050

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ABSTRACT

Under a tension-compression loading condition applied with the frequency of 10Hz and stress ratio of 0.1, the fatigue behavior of the notched aluminum 7050-T7452 coupons was studied using scanning electron microscope (SEM), and SEM-based automated electron back-scatter diffraction (EBSD) that generates images of orientation of grains. The grain microstructure was determined with optical microscope (OM) by employing the lineal intercept method. OM observation demonstrates that the alloy is having a deformation band-based microstructure. The fatigue crack nucleates at grains with high angle (>15 degrees) misorientation in the area characterized by a weak texture and propagates transgranularly.

KEYWORDS: crack nucleation, crack propagation, aluminum 7050-T7452, EBSD

1 INTRODUCTION

Although the study of fatigue cracking behaviour can be traced back to long time ago, the mechanism still remains unclear. Among all the failures of modern metallic materials, fatigue failure is the most important one.

The 7000 series aluminum alloys, due to its combination of high strength, high resistance to stress corrosion cracking, and good fracture toughness, are widely used for structural application in aeronautic industry[1]. Safety is the No.1 requirement of aircraft design at present. Since the Aloha accident, research on the life prediction of aging aircraft structural components has been ongoing in many countries[2].

In order to determine the life of a component, it is necessary to understand the fatigue failure mechanism in the material[2]. Since fatigue cracking is often related to local crystallographically controlled deformation mechanisms or interface properties, a comprehensive understanding of the effect of local crystallography on the cracking behaviour is critical, as also mentioned by many other authors[3, 4].

The EBSD technique is now widely used in various fields of material science to study recrystallisation, phase transformation, and deformation mechanisms, and to link macroscopic metallurgical and/or mechanical properties with local crystallographic properties by collecting crystallographic data from surface analysis. Although electron diffraction technique can be used in TEM and other similar equipment, the SEM based EBSD technique, i.e. orientation imaging microscope (OIM), is far more developed due to relatively easy specimen

preparation and the possibility to study wide areas on the same specimen, giving statistically reliable data sets[5]. Details describing the EBSD technique[6-10] and its application[11, 12] can be found in the recent literature.

This work mainly takes advantages of the SEM based EBSD technique or OIM, as well as SEM to investigate the crystallographic characteristics of the fatigue cracking in aluminum 7050-T7452.

2 EXPERIMENTS

The chemical composition of aluminum 7050–T7452 is shown in Table 1. Aluminum 7050 used in this study is a hand forging alloy. The fatigue test coupon is 13-inch long and 2-inch wide with a notch in the middle, as shown in Figure 1. B=0.25 inches, and r=0.0625 inches.

Standard axial force controlled fatigue tests were conducted at the National Research Council of Canada under constant-amplitude loading, and stress ratio was maintained at +0.1[13]. An ASTM E466 standard smooth specimen with continuous radius between ends (hourglass) was used[4]. The cyclic loading frequency was 10 Hz. The fatigue tests were carried out at room temperature. The fatigue test was stopped when a short crack was detected after190050 cycles.

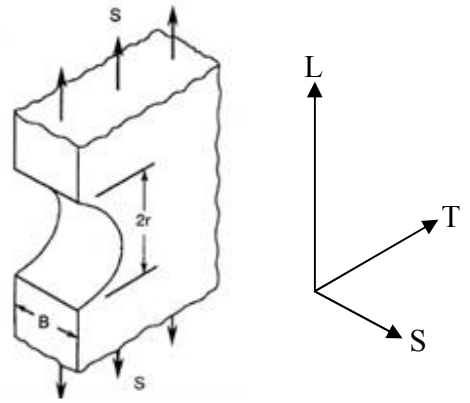


Figure 1 The schematic diagram of the fatigue test coupon and definition of the direction

Table 1 The chemical composition of Al 7050 (in wt%)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Others		Al
									Each	Total	
0.12	0.15	2.0-2.6	0.10	1.9-2.6	0.04	5.7-6.7	0.06	0.08-0.15	0.05	0.15	Bal.

Grain size measurements were carried out with reference to ASTM E 112-96 “Standard Test Methods for Determining Average Grain Size” after the samples were metallographically prepared and etched with Keller’s reagent 3(a) for 10-20 seconds to reveal the microstructure.

The investigations on grain orientation were finished by using a Philips XL 30 Secondary Electron Microscope (FEGSEM) equipped with a DigiView

1612 camera and OIM Data Acquisition System. The EBSD patterns were analyzed using the TSL-OIM Analysis software.

RESULTS AND DISCUSSION

3 Results and Discussion

3.1 Metallographic Inspection

The fractographic image of the cracked sample is shown in Figure 2[16]. The crack nucleates on the surface around the center of the half circle, as indicated by the radial lines shown in Figure 2. Note the front surface of the sample was polished for OIM examination purpose, a thin layer of material (~10 m) was removed and some nucleation features may be removed too.

The sample has an 800μm long crack. Figure 3 displays the SEM image of the central part of the as-fatigued crack path, before the sample was opened. The SEM investigation was expected to identify the location of the nucleation site by finding a cavity or precipitate on this site. However, no precipitates or cavities were found on the surface in this test. The white areas that were examined by EDAX showed the same chemical composition as the matrix. The result indicates that the fatigue crack might not start right on the surface but at a sub-surface.

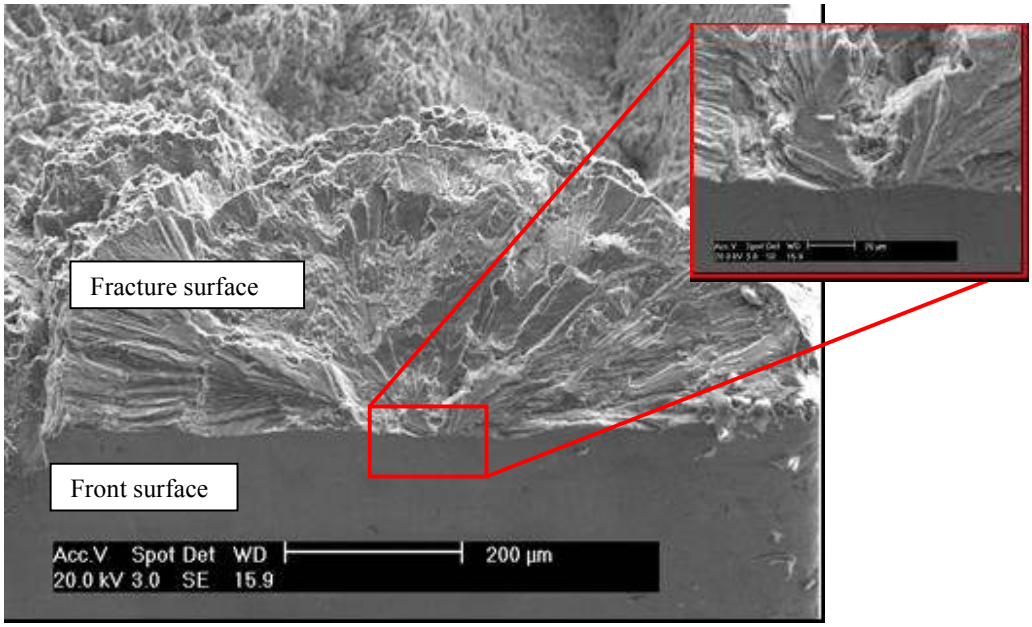


Figure 2 Fractographic images of the cracked sample SL_c (P25) taken apart[13]. Note the front surface of the sample was polished for OIM examination, a thin layer of material (~10 m) was removed and some nucleation features may be removed too.

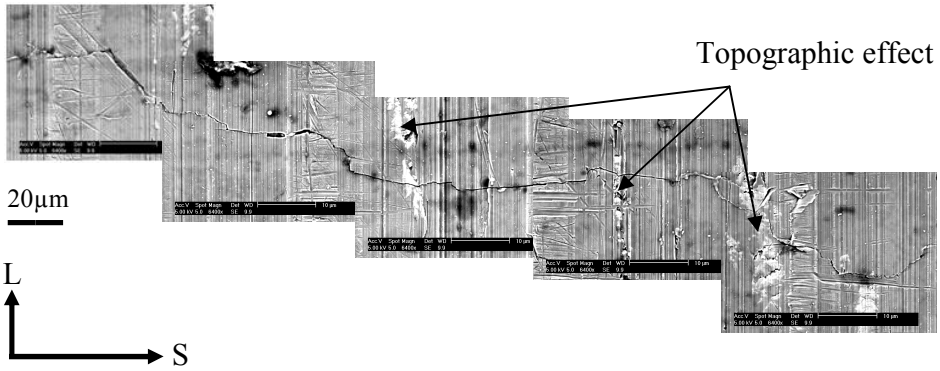
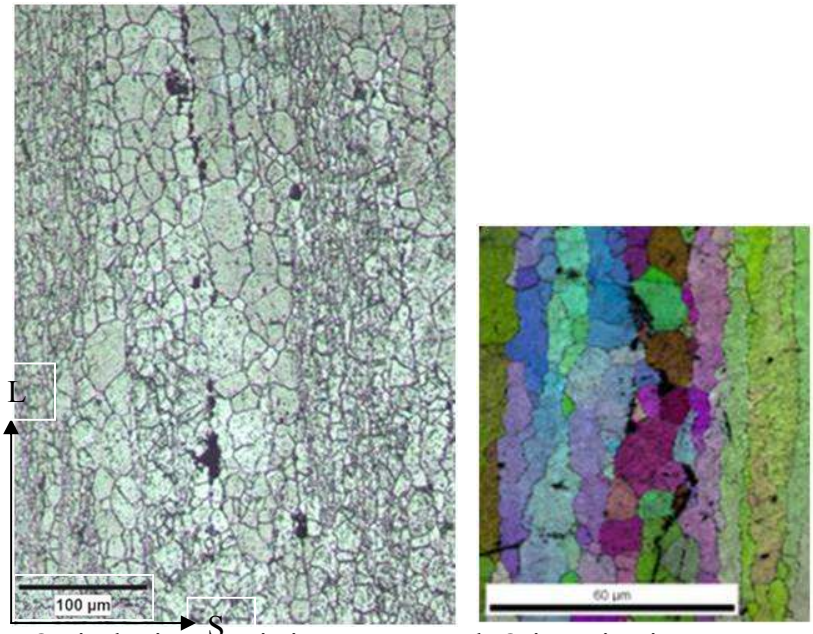


Figure 3. SEM images of the central part of the crack of the fatigued sample

3.2 Grain Size

The optical image (Figure 4 a) displays an inhomogeneous microstructure. LS plane is basically a band-based microstructure with the grains elongated along L direction. These bands were evolved most probably from the forging process. After heat treatment, grains in some area are well recrystallized, where grains are relatively larger and after etching grain boundaries can be clearly revealed, but grains in other area are not well recrystallized, where grains are smaller and after etching grain boundaries cannot be clearly revealed. The later orientation investigation (Figure 4 b) proves the band structure and further reveals that the boundary misorientation of those clearly revealed by Keller's reagent is relatively at high angles (larger than 5 degrees).

The measured grain is ~6μm in terms of mean lineal intercept length. The distribution also displays a skewed right tail which means there are small amount large grains found in the material, and the aspect ratio measurement shows the grains is generally elongated along the longitudinal direction.



a Optical microscopic image b Orientation image

Figure 4. Microstructure of the fatigued sample

3.3 Grain Orientation

Figure 5 is the orientation maps. Five scans were carried out to cover the whole crack path length. Orientation map is the inverse pole figure map which makes use of a color-coded triangle to designate the orientation. Similar colors indicate similar orientation. The result shows that the sample has a preferred {1 0 1} plane orientation on LS plane. The crack mainly propagates transgranularly except the central part highlighted with a white rectangle. The highlighted area is clustered with large grains with random orientation and high angle boundary misorientation. The OIM and SEM pictures on the crack nucleation area are shown in Fatigue 6 (a).

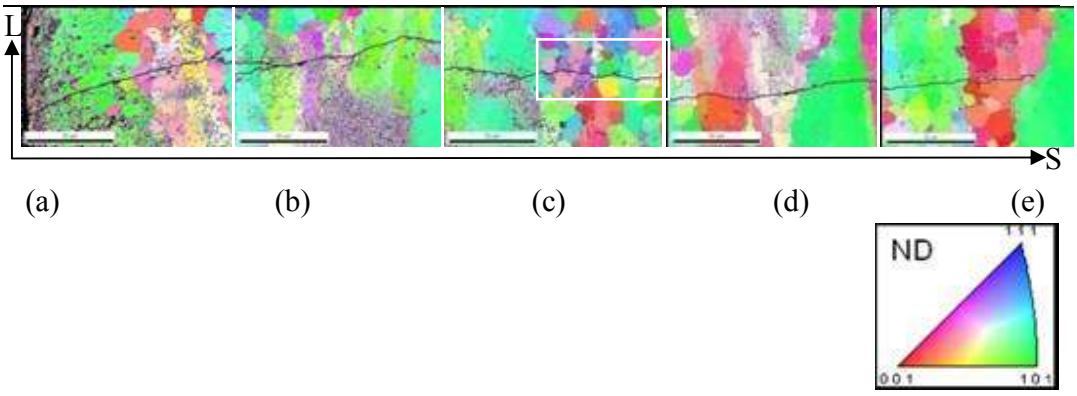
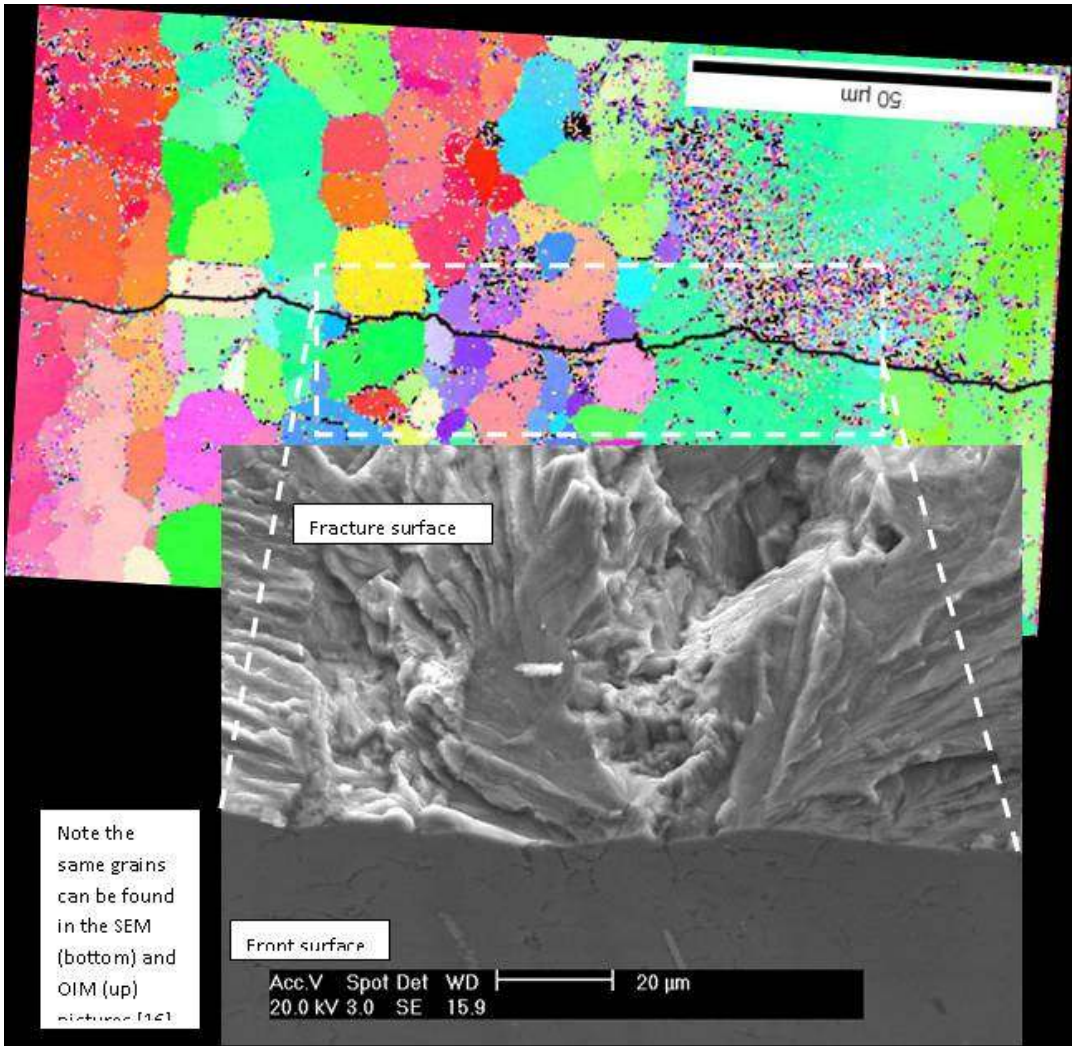
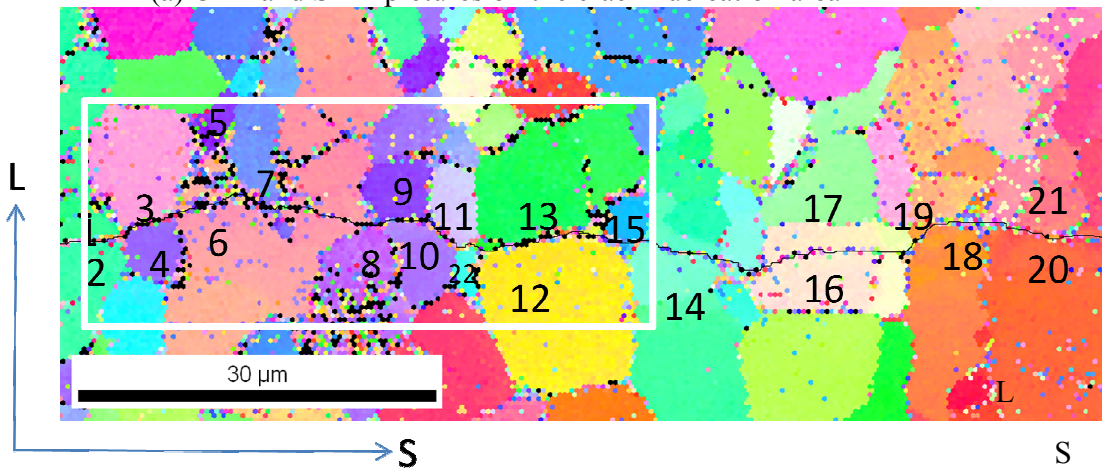


Figure 5 Orientation maps for SL, LT_f, and SL_c



(a) OIM and SEM pictures on the crack nucleation area



(b) OIM misorientation map

Figure 6 The SEM and OIM pictures of the central part of the crack

Table 2 Misorientation angles for the grains along the crack path of the central part

M(3, 4)	M(5, 6)	M(6, 7)	M(9, 10)	M(10, 11)	M(13, 22)	M(12, 13)	M(12, 15)	M(14, 15)	M(16, 17)	M(16, 19)	M(16,18)	M(20, 21)
15°	52°	61°	9°	33°	17°	25°	56°	11°	9°	6°	15°	9°

In Figure 6 b, grains along the crack path are labeled with numbers, and the misorientation angles between the neighboring grains are listed in Table 2. In Table 2, M(x, y) designates the misorientation angle between grain x and grain y. From Figure 6 and Table 2, we notice there are quite a few neighboring grains (grain 1-13, and grain 15, 22) which have high misorientation angle of more than 15°, as shown in the highlighted area with a white rectangle, while other neighboring grains along the crack path generally have a low misorientation angle of less than 15°.

3.4 Deformation Ability

Deformation ability, which is characterized by the Taylor Factor map, indicates how easy or difficult it is for the grains to deform under a certain loading condition. Taylor Factor describes the propensity of a crystal to deformation based on the orientation of the crystal relative to the sample reference frame and the applied stress system. The higher the Taylor Factor, the more difficult the deformation is. In the present measurement, Taylor Factor map was generated with the deformation gradient tensor similar to a tension or compression along the longitudinal direction, as shown in Figure 7. The examined area of Figure 7 is the same as that of Figure 6. The Taylor Factor is designated with a color scale. The nucleation area, as shown in the white rectangle, is surrounded by two blue bands. This sharp difference between the white rectangular area and the surrounded bands suggest the strong deformation incompatibility and favours the crack nucleation.

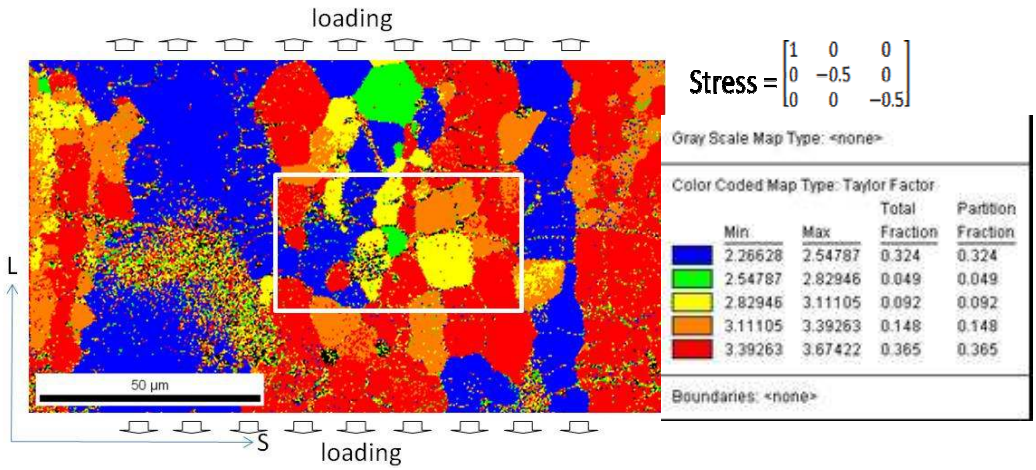


Figure 7 Taylor Factor map of the central part of the crack

4 CONCLUSIONS

The present OIM investigation on the fatigue crack behaviour of aluminum 7050-T7452 demonstrates that the microstructure (grain size, bands) and orientation has a strong effect in the fatigue crack behaviour and allows the following observations:

a) The fatigue crack is more likely to nucleate at the grain boundaries within agglomerate of large grains having high misorientation grain boundaries.

b) The deformation incompatibility may be another factor of favouring the crack nucleation.

ACKNOWLEDGEMENTS

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