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On the role of texture in governing fatigue crack propagation behavior of 2524 aluminum alloy

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ABSTRACT

The texture evolution of AA2524 cold-rolled sheet during annealing process and texture effect on fatigue crack propagation (FCP) behavior were investigated. Results showed the sample annealed at 400 °C for 45 min and solid solution-treated at 490 °C for 20 min had the strongest Goss and P textures, and possessed the lowest FCP rates. EBSD examination indicated Goss, P, Q, Cube, R and S grains induced great crack deflection to retard crack growth, when having large twist and tilt angle component boundary or pure twist boundary with neighboring grains. In the case of small angle boundary or relatively large angle tilt boundary with adjacent grains, Cube, Copper and R grains induced little crack deflection. Additionally, SEM results showed, in the presence of large twist angle component boundary or pure twist boundary, more severely plastic deformation presenting numerous slip bands occurred in Cube, R and S grains than that in Goss, P and Q grains during crack propagation. In contrast, no evident slip bands formed in Cube, Copper and R grains when having small angle boundaries or relatively large tilt angle boundary.

1. Introduction

Plenty of investigations of texture evolution of aluminum alloys have long been conducted during rolling and heat treatments, as the mechanical properties are vitally impacted by the texture developed during processing [1–5]. It is well known that initial textures can convert into stable ones located on the β fiber, which transfers from Brass through S to Copper texture during rolling [1,2]. Recrystallization textures have also been a subject of research by many materials scientists. In this stage, rolling textures are gradually rotated into the common recrystallization textures like Cube [6–9], P [10,11], R [12], Goss and Q [13–16]. However, most of these investigations often focus on the formation of these texture components other than the relationship between texture components and mechanical properties, especially in polycrystalline metals. Recently, researchers [17–19] revealed Goss and part of Cube rather than Brass textures can induce fatigue crack deflection and enhance fatigue crack resistance in Al-Cu-Mg alloy. This suggests that grain orientation plays a vital role in governing FCP behavior. Therefore, it is necessary to reveal more texture components and their effects on fatigue behavior.

As for face-centered cubic (FCC) metals, it has been considered that the microstructural effects, including atom clusters, second-phase particles, grain sizes, grain boundaries, grain orientations and slip bands, play an important role in fatigue crack growth [17–33]. Some researchers [20–22] revealed that the large FCP resistance of Al-Cu-Mg-X alloy was strongly connected with the size of Cu-Mg and Mg-Ag co-clusters. They believed that large co-clusters were difficult to re-dissolve through repeated cutting by dislocations, thereby improving the FCP resistance. Some investigations about the effect of second-phase particles on FCP resistance in aluminum alloys indicated that the enhanced FCP resistance was caused by some special particles like Ω, T_B and T_1 phases [21,23,24]. These shearable particles could enhance slip reversibility and strain localization, which contributed to crack deflection and roughness-induced crack closure (RICC). Both effects potentially led to slow FCP rates. However, it was well known that the presence of large iron- or silicon-rich coarse inclusions was detrimental to the fracture toughness [26,27]. Some researchers [25–27] explored the grain size effect on FCP, but their results did not always suggest that an increased grain boundary area caused by grain-refining could give rise to increasing FCP resistance. As for grain boundary, some investigations confirmed that enhanced FCP resistance was caused by narrowing precipitation free zone (PFZ) at grain boundaries [34,35]. Wang et al.

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[34] revealed that large-angle grain boundaries could impede the passage of persistent slip bands, and subsequently tended to be the nucleation sites for fatigue cracking in various copper crystals. Little evidence exists to illustrate the effect of texture on fatigue crack growth, although comments have been made in the literature on the crystallographic nature of FCP in aluminum alloys. Chen [35] confirmed that grains with high Schmid factors had easily access to the passage of FCP paths with transgranular fracture in AA2524-T3 alloy. In 2000, Zhai et al. [17] proposed a crystallographic mode which took into account both crack-plane twist and tilt effects on crack retardation at grain boundaries in planar slip bands. And relative interpretation about the growth behavior of the short cracks was given in this reference. Likewise, Wei et al. [36] recently also revealed that fatigue behaviors like inter/transgranular crack, crack deflection or bifurcation relied on local microstructural characteristics, such as grain orientations and geometries. Although all these fatigue behaviors have been attributed to texture effect, definitive proof and relative mechanisms are still awaited. In 2005, Zhai et al. [18] revealed that short fatigue cracks failed to propagate across Goss grains but could easily get across Brass grains in 8090 Al–Li alloy. Liu et al. [19] recently confirmed the different effects and mechanisms of Goss, Cube and Brass grains on the long crack growth in AA2524 alloy. Results showed that Goss, other than Brass grains, were detected to possess large twist angle component boundaries with the neighboring grains. This enhanced crack deflection in fatigue stage II. Nevertheless, it is still unknown, in commercial AA2524 alloy, whether other oriented grains like P, Q, R, S and Copper grains have the similar mechanism and effect on fatigue behavior in stage II.

In near threshold region, the plastic deformation zone size at fatigue crack tip is smaller than one grain size [18,19,37,38]. However, in Paris regime, the plastic deformation zone at crack tip can increase to a larger size up to tens or hundreds of grains with increasing stress intensity factor range [22,39,40]. That is to say, the plastic deformation zone at fatigue crack tip can involve in tens or hundreds of grains with different orientations. These different oriented-grains, in no doubt, exhibit different plastic deformability, which influences slip band formation in these grains. Besides, Chen [35] recently claimed that fatigue crack preferred to propagate through those grains with large Schmid factors. This suggests grain orientation greatly influences FCP path, leading to a different FCP resistance. Evidently, the resistance for different oriented grains to retard fatigue crack growth in Paris regime, can be revealed by analyzing slip band formation in different oriented grains near crack path. So far, however, no literature reported the relationship between grain orientation, slip band formation and FCP path.

Accordingly, based on previous work [19], the present paper mainly focused on investigating the role of textures, including P, Q, S, Copper and R, in governing FCP behavior. In addition, it was first characterized and revealed the relationship among FCP path, grain orientation and slip band formation via SEM and EBSD techniques in fatigue stage II in the present AA2524 alloy sheet.

2. Experimental

Commercial alloys AA2524 hot rolling sheet (8 mm thick) was used in this study. Its nominal composition was 4.0% Cu, 1.4% Mg, 0.6% Mn, 0.02% Ti, 0.06% Fe, 0.06% Si (in wt%) and the remainder Al. The as-received sheet was cold rolled to 2 mm thick and the following heat treatment was present in procedure I of Table 1. All samples used in this paper were gotten from the center of the rolled sheet. Besides, in procedure 1, because of the difference of annealing temperature, all four investigated samples were respectively named as $A_{300–60}N$, $A_{350–60}N$, $A_{400–60}N$ and $A_{440–60}N$.

Table 1.
Experimental procedures of cold rolling AA2524 alloy sheet.

Procedure	Experimental process
I	Annealing at 300 °C, 350 °C, 400 °C and 440 °C/60 min + 490 °C/20 min + Water quenching + Natural aging (named as samples $A_{300–60}N$, $A_{350–60}N$, $A_{400–60}N$, $A_{440–60}N$, respectively).
II	Annealing at 400 °C/(0, 15, 30, 45 and 75)min + 490 °C/20 min + Water quenching + Natural aging (named as samples $A_{400–0}N$, $A_{400–15}N$, $A_{400–30}N$, $A_{400–45}N$ and $A_{400–75}N$, respectively).

Note "A" means annealing, the subscript numbers like $_{300–60}$ stand for annealing at 300 °C for 60 min, "N" means natural aging.