Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 5 (2017) 263–270

Structural Integrity Procedia

www.elsevier.com/locate/procedia

2nd International Conference on Structural Integrity, ICSI 2017, 4-7 September 2017, Funchal, Madeira, Portugal

Material Influence on Crenellation Effectiveness in Damage Tolerant Design

Jin Lu[a], Volker Ventzke[a], Norbert Huber[a] and Nikolai Kashaev[a]*

[a]Institute of Materials Research, Materials Mechanics, Helmholtz-Zentrum Geesthacht, Max-Planck-Str. 1, 21502 Geesthacht, Germany

Abstract

Crenellation is a novel concept to heighten the fatigue resistance of the airframe structures without increasing weight. In this work the impact of materials on the effectiveness of crenellations was investigated. Two candidate alloys for future fuselage skin: AA2139 and AA2198 were selected for this task. Firstly the microstructure and texture of those materials were investigated. Then flat and crenellated panels made of the two alloys were tested under service-related biaxial loading conditions. A removable δ_5 clip gauge was applied at the crack tip to monitor the crack closure behavior during the fatigue tests. After fatigue tests the fracture surfaces were examined to interpret the respective fatigue behavior. It was found that sharp textured AA2198 alloy, which also showed tortuous shear lip morphology, has higher fatigue resistance and larger fatigue life improvement of crenellations compared with the nearly randomly textured AA2139 alloy. The correlation between the sharp texture and tortuous shear lip morphology was discussed. The source of the additional fatigue resistance and the increased crenellation efficiency in AA2198 was also analyzed.

Peer-review under responsibility of the Scientific Committee of ICSI 2017

Keywords: Airworthiness; damage tiolerant design; fatigue crack propagation; AA2139, AA2198; microtexture

1. Introduction

Fatigue is one of the utmost important concerns in the design of airframe structures. Statistics show that about 60% of failures in aircraft components are caused by fatigue damage (Bhaumik et al., 2007). To safeguard the structural integrity of aircrafts from fatigue problems, the damage tolerance approach is usually adopted. This approach requires

* Corresponding author. Tel.: +49-4152-87-2536; fax: +49-4152-87-42536.
E-mail address: nikolai.kashaev@hzg.de

2452-3216 © 2017 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the Scientific Committee of ICSI 2017
10.1016/j.prostr.2017.07.130

periodic inspections on airframe structures to detect and repair small cracks before they become a threat. The growth speed of these cracks from a detectable size up to an allowable size determines the necessary inspection frequency and the operational cost of the aircraft (Goranson, 2007).

To retard the growth of fatigue crack in the airframe structures as much as possible, efforts are made generally in two different approaches. The first approach is to toughen the material against fatigue crack propagation. The toughening mechanism can have either intrinsic or extrinsic sources according to Ritchie (1988). The intrinsic toughening is achieved by enhancing the inherent microstructural resistance to cracking (e.g. modifying the precipitates, changing the bond strength). A good example of this is the optimized damage tolerance properties of the AA2139 and AA2198 alloys developed in recent years (Morgeneyer, 2008; Tsivoulas, 2010). On the other hand metallic materials can also be extrinsically toughened by so-called crack tip shielding mechanism. In such a case premature crack closure can occur at a certain load level above the minimum load during the cyclic loading. This can significantly reduce the effective driving force of crack growth (Schijve, 2009). The crack closure is mostly due to the residual plastic deformation at the crack tip and the misfit of crack surface at asperities, which is even pronounced when large relative sliding of the two crack surfaces occurs such as under mixed mode loads (Seo et al., 2012; Fonte et al., 2006; Freitas et al., 2011; Akhurst et al., 1983).

In aluminum alloys, the primary structural materials for airframes, the crack closure behavior is frequently reported to be related with shear lips on the fracture surface (Schijve, 2009). Shear lips are the slant regions of crack surface (mostly 45° inclined) where the tensile mode decohesion is replaced by the shear mode. Either single or double shear lips can occur at the surface, where the plane-stress state exists. After initiation they are broadened towards the center until a stable shear lip width is achieved (Zuidema and Krabbe, et al., 2005). Since shear lips are usually the highest points of the fracture surface and the residual plastic deformation is also the largest at the surface where the shear lips normally form (Materna and Oliva, 2005), crack closure is frequently observed to occur at shear lips (Schijve, 1988). The morphology of shear lips is also reported to have influences on the crack tip shielding effects (Zuidema and Krabbe, 1997).

Another approach to retard the fatigue crack growth is to modify the driving force via optimization of structural design. The concept of crenellation is such a promising approach, which has the potential of enhancing the fatigue performance of the structure without introducing additional weight (Uz et al., 2009; Muzzolini and Ehrström, 2004; Bucci, 2006; Ehrström et al., 2005). By a systematic thickness variation of the fuselage skin (Fig. 1(a)), the fatigue crack is retarded and accelerated in specific regions. In a well-designed crenellation, the fatigue life gain in the retardation region is much larger than the fatigue life loss in the acceleration region. This leads to an overall fatigue life improvement. It was demonstrated that crenellations lead to a 9% fatigue life improvement in unstiffened panels and a 65% improvement in stringer-stiffened panels (Uz, 2010).

So far the two aforementioned approaches were only studied separately. However, it is quite possible that the fatigue life improvement via crenellations depends also on the material used. The efficiency of crenellations could be further enhanced if the interaction between the material and geometrical factors is well understood (Lu et al., 2015a). Thus the aim of this study is to investigate the possible influence of materials on the effectiveness of crenellations. Two candidate alloys for future airframe structures: AA2139 and AA2198 are used in this study for their significant inherent difference. Firstly the grain structure and texture of the two materials were characterized. Then, the fatigue behaviours of flat and crenellated panels made of each material were examined respectively. Possible clues to understand the observed fatigue behaviour were obtained through the subsequent fracture surface examination.

2. Materials and methods

Metal sheets of the materials AA2139 (4.5 mm thick, T351 heat treatment condition) and AA2198 (5 mm thick, T3 heat treatment condition) were investigated in this study. The grain structure and texture of both materials were investigated using optical microscope and EBSD analysis. Samples for metallographic observation were sectioned parallel to the longitudinal/transverse (L-T) plane, the normal/longitudinal (N-L) plane and the normal/transvers (N-T) plane respectively. The EBSD analysis was performed on N-L sectioned specimens so that the possible variation of texture in through-thickness direction resulted from rolling process can be examined. The magnification at SEM during the EBSD analysis is 500× for AA2198 and 100× for AA2139.