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Review

Experimental and analytical investigation of fatigue and fracture behaviors for scarfed lap riveted joints with different lap angle

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ABSTRACT

Fastener load-transferred experiments and fatigue tests of the scarfed lap riveted joints with different lap angle were carried out. The fracture surfaces were observed by optical microscope (OM) in this paper. Both experimental and computational studies were described and compared when possible. Based on the qualitative finite element analysis (FEA), the multi-axial fatigue life of the scarfed lap riveted joints has been predicted by Smith–Watson–Topper (SWT) method and Wang–Brown (WB) method respectively. Both of the test results and predicted results show that fatigue life of scarfed lap riveted joints is remarkably increased after introducing lap angle into the faying surface. 8 mm-thick specimens with the lap angle of 1.68 °C exhibit the best fatigue performance, and 20 mm-thick with the lap angle of 3.37 °C do in the present study. Compared with the result of WB theory, the result of SWT theory is more conservative and reliable. For structures' reliability designs, SWT theory and WB theory are all fallibility.

1. Introduction

Over the past decades, many efforts have been dedicated to understanding the fatigue damage of airplane structure. The distinguishing feature of the structure details can be used to represent the durability of airplane structures. The reliability of airplane structure relies on details, such as fillet, bolt and fastener holes [1]. Catastrophic fatigue fracture of airplane structure is often due to the initiation and propagation of fatigue crack closed to fastener holes. According to statistic, fatigue fracture of fastener holes account for 50–90% of fracture of aging plane [2].

By this time, the fatigue experiments of riveted joints or bolted joints have been studied by many scholars. Park et al. [3] proposed fatigue test methods that have the goal of discerning material performance and they described a generic test procedure to evaluate materials for low load transfer and high load transfer airframe joints. The effects of various parameters on joint properties by designing different manners of joints are also studied. They also described the effect of fastener load transfer on the cracking behavior at countersunk fastener holes by experimental and computational methods [4]. Liu et al. [5] has studied the bolt clamping force on the fatigue performance of fastener holes. Ralph et al. [6] have studied the effect of various aircraft production drilling procedures on hole quality. The effect of surface processing, such as shot peening [7], cold expansion [8] on fatigue performance of fastener holes was studied qualitatively. Urban [9] provided a brief review of literatures searched on fatigue life of riveted airframe sheet metal joints and researched the parameters affected fatigue life of joints. Load transfer and stress distribution were simulated by three-dimensional finite element analysis.

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Starikov [10] tested and analyzed the fatigue behaviors of aluminum alloy joints. He found that the friction wear between the joint parts significantly affected the fatigue behaviors of the inspected joints.

Many structures used in the aircraft usually undergo multi-axial loading, such as the aircraft fuselage and wing skin structure. Multi-axial fatigue is more complicate than uniaxial fatigue. Studies on the multi-axial fatigue damage and the method of life prediction have not only the important significance, but also a practical value for the design of structures and components. Smith et al. [11] offered a classic multi-axial fatigue criterion, and Sum et al. [12] developed incorporating the Smith–Watson–Topper (SWT) multi-axial fatigue criterion based on the finite element analysis, and the fatigue life prediction of simple and complex contact configurations were also presented. Considering material non-linearity, Noll et al. [13] studied the fatigue life simulation of multi-axial CFRP laminates.

Previous researches mainly focus on a clinic lap joint, which is commonly used in fuselage and airfoil. As a novel structure, the scarfed lap joint wherein a lap angle was introduced into faying surface has rarely been reported. The design of details and fatigue performance are not available in literature. The scarfed lap joint has many advantages over the aclinic lap joint. The most important feature for scarfed lap joint is the lap angle, which has a dramatic influence on its fatigue performance. The lap angle introduced into the faying surface is effective in averaging load transfer of fasteners. Consequently, stress concentration around the hole was reduced remarkably.

In this paper, fastener load-transferred experiments and fatigue tests of the scarfed lap joints riveted joints were carried out, and the fracture surfaces were observed by optical microscope (OM). Finite element analysis (FEA) were carried out to find out the optimal lap angle. The FEA results showed a good agreement with the experiment result. Based on the finite element analysis (FEA), the multi-axial fatigue life of the scarfed lap joints has been predicted by Smith–Watson–Topper (SWT) method and Wang–Brown (WB) method respectively. The results of FEA were compared with the experiment results.

2. Specimen and the tests setup

The geometry of two types of the scarfed lap joint specimens was illustrated in Fig. 1, including 8 mm-thick specimens and 20 mm-thick specimens. The assembled specimens contain four rows and two columns of countersunk rivets. The jointed sheets are made of aluminum alloy 2024. The countersunk rivets used here are made of titanium alloy.

Prior to fatigue tests, three static tests were performed in order to study the real load transfer of the scarfed lap joints. The strain foils were attached in the 22 positions shown in Fig. 2. Scarfed lap joints with strain foils were shown in Fig. 3. After that, all the specimens were tested on a servo-hydraulic fatigue testing machine Instron 8802 (shown in

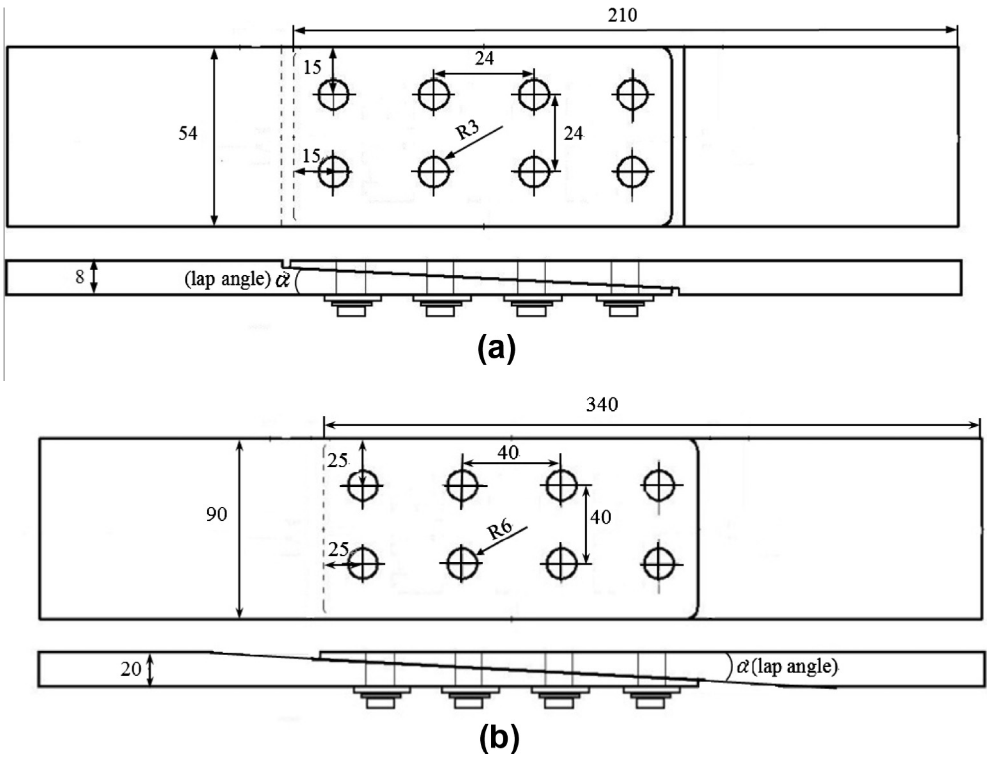

Fig. 1. Specimen diagram (Unit: mm): (a) 8 mm-thick, (b) 20 mm-thick.