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Fatigue crack location and fatigue life for riveted lap joints in aircraft fuselage

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ABSTRACT

Effects of variables related to design and production of riveted lap joints representative of longitudinal sheet connections for a pressurized transport aircraft fuselage were experimentally investigated. Specimens from an aircraft Al alloy D16Cz Alclad sheets of three different thicknesses (1.9, 1.2 and 0.8 mm) were assembled under load control using round head rivets and rivets with the compensator from a P24 Al alloy. For the joints from 1.9 mm thick sheets fatigue tests indicated a dependency of the crack initiation site and crack path on the squeeze force level and on the rivet type. At the same time, increasing the squeeze force led to improved fatigue properties of the joints, specimens assembled using the rivets with the compensator showing fatigue lives longer than joints with the round head rivets. All observed trends have been explained based on hole expansion and load transfer measurements. For thin sheets connected using the round head rivets, local deformations under the rivet driven head arising during the rivet installation promoted crack initiation and failure in the adjacent sheet. Fatigue test results indicated that the detrimental effect of this type imperfections could outweigh the benefits associated with a decrease in secondary bending due to thinning the sheets. The rivets with the compensator were observed to cause significant local imperfections beneath the manufactured head, which adversely affected the fatigue performance of the joints from thin sheets.

1. Introduction

Riveting remains a preferred method for connecting elements of an aircraft structure, though adhesive-bonded and riveted–bonded joints are also applied. A typical connection of sheets in a pressurized transport aircraft fuselage in the longitudinal direction is a riveted lap joint, usually comprising three rivet rows, as shown in Fig. 1.

The fuselage skin and its stiffening elements carry flight loads arising from a combined effect of cabin pressurization, air turbulences, manoeuvres, and the aircraft weight. The resulting membrane stresses in the longitudinal lap joint connections of the skin strongly depend on the circumferential location of the splice, its position along the fuselage and the stiffeners' design solution, examples of which can be found in Ref. [1]. The hoop (circumferential) stress due to a differential pressure between the cabin pressure and the atmospheric pressure is about two times larger than the longitudinal stress. Therefore, the hoop stress is a primary loading for the skin joints in the longitudinal direction. The maximum hoop stress level in the skin can vary between 80 and 120 MPa, depending on the cruise altitude and aircraft type [2].

Laboratory tests on riveted lap joint specimens are typically carried out under uniaxial, constant amplitude fatigue loading simulating the hoop stress variations in the fuselage skin. Experiments indicate that for flat specimens such tests provide conservative results on the fatigue performance under biaxial loading [3,4]. Furthermore, no significant effect of a longitudinal stringer on the specimen fatigue life was found in the above mentioned works.

In laboratory tests, a single load cycle is equivalent to the pressure cycle of the cabin, the uploading and unloading corresponding to the aircraft climb and descent respectively. Load frequencies in fatigue tests are higher than those corresponding to the duration of the climb period, which is relevant for crack growth. Literature results reveal that loading frequency in constant amplitude tests seems to be of little importance for the tests results [5].

When uniaxially loaded specimens are tested, the so-called edge effect (difference in the lateral contraction for two overlapping sheets) occurs, which leads to a premature crack initiation in edge columns of rivets. Measures that can be taken to avoid the edge effect are overviewed in Ref. [6].

Lap joints in the fuselage structure are curved. Fatigue tests indicate faster crack growth and shorter fatigue lives for curved specimens than for flat specimens with the same riveted lap joint configuration [6]. This effect must be recognized when considering correspondence between test results for simple laboratory specimens and properties of the real fuselage structure. Nevertheless, uniaxial tests on small flat specimens prove useful for parametric studies. Especially, they provide information on the influence of

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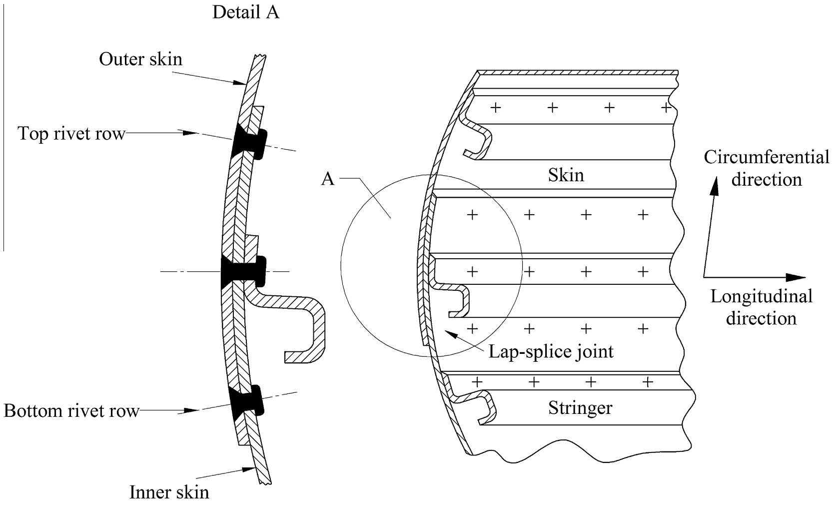

Fig. 1. Typical fuselage longitudinal riveted lap splice joint.

production variables and design parameters on the in-service fatigue behaviour of joints.

Even in the case of simple riveted lap joint specimens under uniaxial loading, their fatigue behaviour is affected by many variables, often interrelated, associated with joint design and production and the stress level. Fig. 2 illustrates schematically the resulting, extremely complex implications for the joint fatigue response represented by the fatigue crack initiation location, the crack shape and path, and the joint fatigue life. The installation of a rivet induces rivet hole expansion and residual clamping between the sheets. Local residual membrane stresses generated due to hole expansion have a strong impact on all aspects of the joint fatigue response. The influence of hole expansion occurs also through its effect on rivet flexibility and, hence, load transmission by the joint [7]. Residual clamping gives rise to friction between the sheets under applied loading. Friction promotes fretting fracture, accounts for some of the load transfer through the joint and, consequently, it can have a profound impact on the joint fatigue performance. Due to lap joint eccentricities, the so-called secondary bending is induced under nominally axial loading on the sheets. Its magnitude depends on the joint configuration in the thickness direction and the applied load level and can be affected by the residual clamping. Secondary bending can lead to considerably elevated tensile stresses in the sheets and affects both the mode of failure of the joint and its fatigue life. All dependencies presented in Fig. 2 are analysed in detail in a recent book [8].

In this paper, experimental data on the influence of the squeeze force, rivet type and sheet thickness on the fatigue behaviour of riveted lap joints representative for the pressurized aircraft fuselage are produced. An interpretation of the observed trends is given invoking results on rivet hole expansion and load transfer measurements as well as allowing for imperfections of the joint that can arise for some rivet type/sheet thickness/squeeze force configurations.

2. Design and production of riveted specimens

The geometry of riveted lap joint specimens used for the fatigue tests is shown in Fig. 3 and the dimensions are given in Table 1. The rivet row spacing $s = 5d$ (d – rivet diameter) and the rivet pitch in

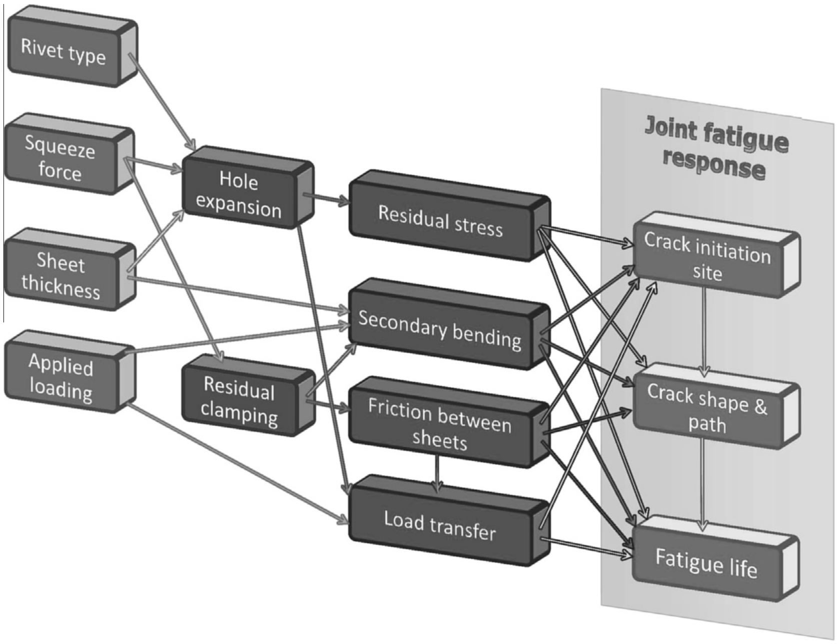

Fig. 2. Factors influencing the fatigue response of a riveted lap joint.