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Fatigue Behaviour of Bolted Joints without Load Transfer

Martin Kadlec[1, a], Ivan Mlch[1,b] and Roman Růžek[1,c]

[1]VZLU – Aerospace Research and Test Establishment, Beranových 130, Prague, Czech Republic

[a]kadlec@vzlu.cz, [b]mlch@vzlu.cz, [c]ruzek@vzlu.cz

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Abstract. The fasteners affect the fatigue performance which significantly influences lifetime of aeronautical structures. The aim of the experiments was to determine and compare the fatigue characteristics of typical joints with various fastener types applied in L 410 NG airframe structure. The bone shape specimens with hole filled by fastener were used. Fatigue behaviour of two materials 7475-T7351 and of 2124-T851 and two types of Hi-Lite bolts and LeN 3366.5 rivets were investigated. Constant force amplitude loading with stress ratio of 0.05 and frequency of 5 Hz were applied. Four types of failure modes were described for each specimen according to the crack initiation site. Due to various invalid failure modes, no difference among the configurations was determined as significant.

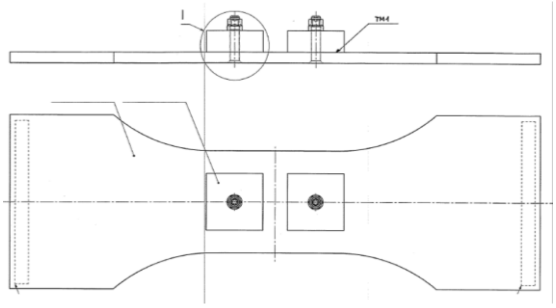
Introduction

Bolts and rivets are typically used for joining of metallic parts used in aircraft wing structures. The fasteners as well as joint design, production quality and stress level affect the fatigue performance which is fundamental for aeronautical structures [1, 2]. The fatigue properties of joints can be critical for several reasons: stress concertation, fretting corrosion, eccentricity producing secondary bending [3]. Fatigue behaviour of an aircraft is typically determined on specimens with stress concentration that is representative for the real structure. The typical stress concentration for a riveted small commuter aircraft is defined by value of 2.6. Moreover additional technological factors such as riveting, hole expansion, or tightening torque which can significantly affect the fatigue life have to be evaluated. Therefore, specimens with a hole filled by the actual fastener are used. The aim of this paper was to evaluate fatigue behavior of the joints without load transfer. The results are to be utilize in the framework of life enhancement of principal critical areas in a wing structure.

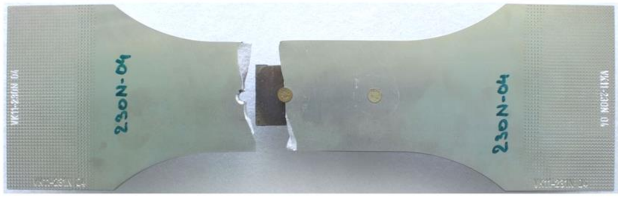
Materials and Methods

The experiments were performed on joints consisting of a bone shape main part and two blocks presenting ends of a joined part (Fig. 1a). Test matrix in Table 1 shows two types of materials that were used: 76.2 mm thick plate of 7475-T7351 and 100 mm thick plate of 2124-T851. Two types of fasteners were used: Hi-Lite bolts and rivets LeN 3366.5. For the Hi-Lite bolts, hermetic was used [4, 5]; for the LeN rivets, no hermetic was used. The joints were loaded by constant amplitude with $R = 0.05$ and frequency of 5 Hz at room temperature. Various plate thicknesses from 2.2 mm up to 11.3 mm and different rivet diameter combinations were analysed based on the structure of L 410 NG airplane. The fatigue tests were performed on INOVA ZUZ 100 kN and Hydropuls Schenck 250 kN.

The photo documentation of the fracture surface was obtained by Canon EOS 500D using side halogen lighting.



a) Schematic drawing of unloaded joints.



b) Valid failure from rivet hole

Fig. 1: Unloaded joint schematic and a failure mode

Results

Regression model evaluation. First, a linear regression model and then a nonlinear model in compliance with MMPDS-11 [6] were applied for series with at least four specimens with valid failure mode.

A nonlinear regression model is represented by the expression:

$$\log(N) = A_1 + A_2 \cdot \log((\sigma_{br})_{MAX} - A_4), \quad (1)$$

where A_1 , A_2 and A_4 are the regression constants and $(\sigma_{br})_{MAX}$ is the maximal stress level of the load cycle applied to the specimen gross cross section. The linear model was used as Eq. 1 with A_4 = 0. Fig. 1b shows the obtained two valid Wöhler curves. The other curves were not evaluated due to invalid failure modes.

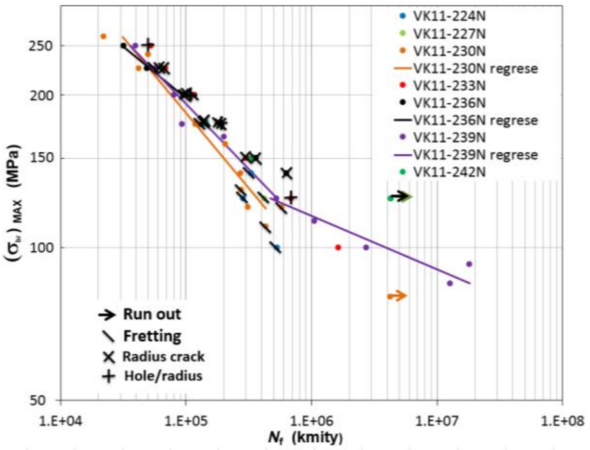
The fatigue data are also marked according to failure type that is described in the following paragraph. No point crossing means valid crack initiation from the hole. Fig. 2 shows summary of the fatigue lives including linear and non-linear regressions. The linear regression was split into two parts because of different slope for load below 120 MPa.

Table 1: Specimen parameters.

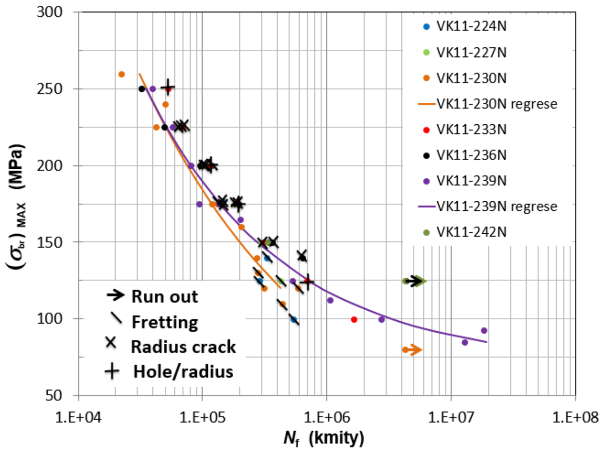
Joint series ID	Qty.	Main part		Opposite part		Fastener spec.	
		t_1 (mm)	Material	t_2 (mm)	Material	ID	dia. (mm)
224N	12	7.5	7475-T7351	10	2124-T851	HST10AG8	6.3
227N	12	10	2124-T851	7.5	7475-T7351	HST10AG8	6.3
230N	12	5.7	7475-T7351	11.3	2124-T851	HST11AG6	4.8
233N	12	11.3	2124-T851	5.7	7475-T7351	HST11AG6	4.8
236N	12	7.2	2124-T852	3.5	7475-T7352	5Du Zk 5x	5
239N	12	3.5	7475-T7354	2.2	2124-T854	5Du Zk 4x	4
242N	12	2.2	2124-T854	3.5	7475-T7354	5Du Zk 4x	4

Failure modes. Failure modes were described for according to the crack initiation site as follows:

1) Fracture initiated from the fastener hole which was considered as the only valid failure. The top surface view is included in Fig. 1b. The fracture surface in Fig. 3a shows radial crack growth from the fastener countersunk;



a) Linear regression model.



b) Non-linear regression model.

Fig. 2: Results of fatigue crack growth of unloaded joints.

2) Fretting corrosion between main and opposite part was observed only for the Hi-Lite fasteners (Fig. 3b). The fretting initiated not only from the opposite block corner but also from its edges.
3) Specimen radius crack initiation, more preferentially for higher load levels over 150 MPa (Fig. 3c).
4) Longitudinal cracking. It was observed for specimens with the radius initiation and it appeared only for main parts extracted in LS direction.

a)
b)
c)

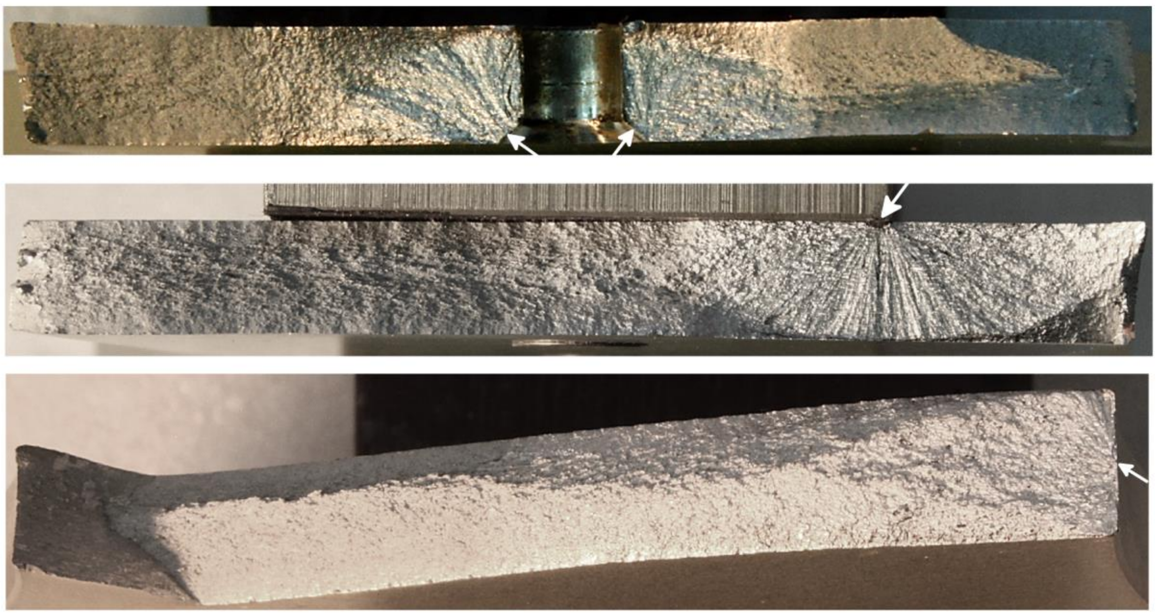


Fig. 3: Typical failure observed during testing: a) hole initiation, b) fretting corrosion, c) radius initiation.

Discussion

There is a possibility that some of radius failed specimens had already hole initiated crack. Detailed non-destructive inspection of holes (after joint disassembly) was not performed. This idea is supported by the fact that the radius initiated fatigue lives were not significantly different from the valid failure modes. However, a combination of radius initiation and fretting corrosion was confirmed on several specimens. Testing of series with high ratio of the invalid failure modes was interrupted. The specimens with other than hole crack initiation were not included to the evaluation.

At least 10 specimens are needed for a valid Wöhler curve according to standard [2] that was met only for series 239N. Therefore, only the 239N curve parameters can be used for modelling and no comparison of curves is possible. It is recommended to complete number of the regular results by means of additional experiment. For additional test design and realization following recommendation are suggested:

1) Design modified specimens with a large or double radius (larger radius near the gage section) to prevent radius crack initiation.

2) Use lower cycling frequency for Hi-Lite bolt specimens to prevent fretting which can be done on the remaining specimens. Some additional research activities are needed.

Conclusion

Several Wohler's curves for various configurations was determined for various combination of thickness and fastener type. Due to various invalid failure modes, no difference among the configurations was determined as significant. To clarify the fatigue data trends, two regression models were used (linear and non-linear equation). There were several types of invalid failure modes. Fretting corrosion between main and opposite part occurred for Hi-Lite fasteners. The fretting corrosion initiated not only from the opposite block corner but also from its edges. Especially for load levels, fatigue crack initiated from the radius surface. Additionally, longitudinal cracking was observed for specimens with the radius initiation and it appeared only for main parts extracted in LS direction.

The two valid Wöhler curves will be used for modelling. For additional test design and realization, modified specimens with a large or double radius to prevent radius crack initiation are recommended. Using lower cycling frequency for Hi-Lite bolt specimens should prevent fretting corrosion.

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