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The Fatigue Strength of Various Mechanical Double Shear Rivet Joints of D16čA TV Sheets

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Abstract. This paper describes the fatigue test results and evaluation of various double strap but joints (Solid-rivets, CherryMax) of D16čA TV aluminum alloy sheets which are representative for commuter aircrafts. The aim of the tests was to determine and compare the fatigue behavior of typical double shear joints with various fasteners. The solid-rivets with round head and compensator showed the best fatigue performance.

Introduction

The load carrying capacity and fatigue resistance of joints depends on many structural, manufacturing and material factors like: connection type (overlap or butt, symmetric or asymmetric), size, rivet pitch and spacing (distance between rivets and rivet rows), sheet thickness, diameter of rivet shank and rivet type (i.e. universal, mushroom or countersunk). The most advantageous stress states occur for symmetric joints where uniaxial or biaxial tension is dominant. Unfortunately, they can be rarely used in practice. The non-symmetric joint is very unfavorable because of eccentric tension (secondary bending). The secondary bending influence is estimated by comparison of maximum bending stress in the concentration area with the nominal stress in the reduced section or with local tension stress. Additional technological factors such as riveting or holes expansion, which can also significantly affect fatigue durability, have to be taken into account [1, 2, 3].

The paper deals with a double shear joint. The typical fastener used for joining of metallic parts in commuter airframes is a rivet. The rivets are used mainly for a skin-stringer, skin-skin, skin-frame, etc. connections. In this sense the aim of presented experimental investigations was to define and compare the fatigue strength of typical riveted double strap butt joints with using of different types of fasteners. Five different joint configurations were considered. Individual joints differ in rivet row pitch, a number of rivets and type of rivet used. The methodology of fatigue tests was based on fatigue loading until failure whereas, after the failure of one joint, the specimen was split up to enable further testing of remaining joints of the specimen. The results will be applied to achieve life enhancement of principal critical areas, verification manufacturing technology and to compare calculations with the real data.

Materials and Methods

Five sets of double-riveted double strap butt joints were considered for fatigue evaluation. The overall shape of all specimens was the same – they differ in rivet row pitch, a number of rivets and type of rivets. Each set consisted of 6 pieces of test specimens. Every specimen contains the same four riveted joints in series. Scheme of the test specimen is shown in Fig. 1. After a failure of the first double lap shear joint of the specimen, the specimen was split up to enable further testing of remaining joints of the specimen. Top and bottom straps (sheet 1,3), and middle sheets (sheet 2) were made from D16čA TV aluminum alloy. The five different rivet types was used - round head (RH) solid rivet with and without compensator, countersunk head (CSH) solid rivet with compensator, CherryMax 3, and CherryMax 4 rivets. Examples of the main differences between individual rivet joints are shown in Fig. 2. Configurations of individual batches are shown in Tab.1.

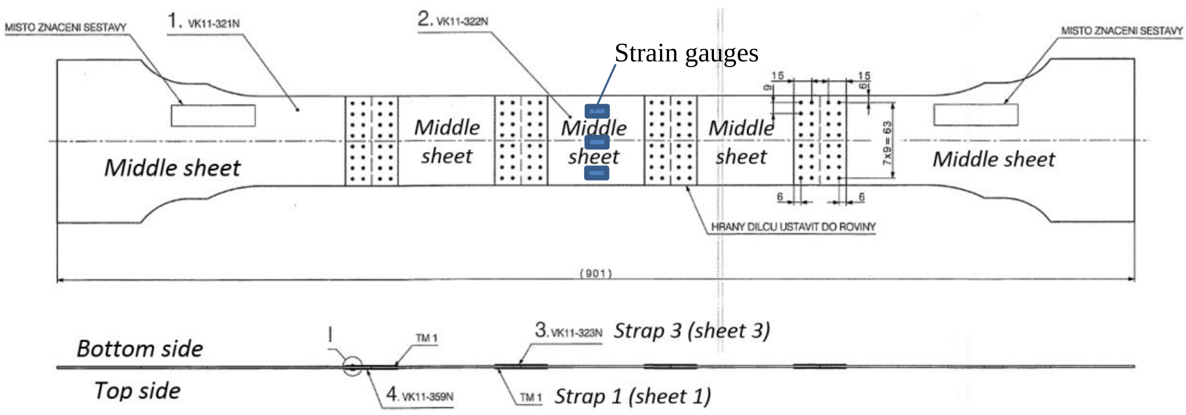

Fig. 1 Schematic drawing of double shear rivet joints

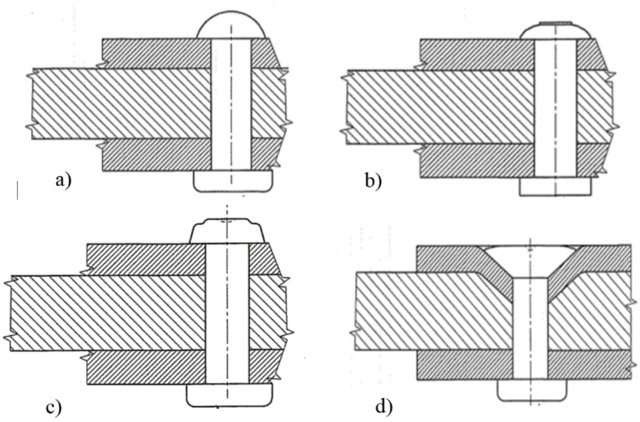

Fig. 2 Example of used rivet types (RH rivet without compensator (a), CherryMax with compensator (b), RH rivet with compensator (c) and CSH rivet with compensator (d))

One specimen from each batch was equipped with strain gauges in its middle part on the middle sheet surface for monitoring of stress uniformity during loading. The strain gauges location is shown in Fig. 1 using blue rectangles. Six strain gauges (back-to-back) were installed on the first tested specimen (from the CherryMax4 batch).

The double sheet rivet joints were loaded by a monotone loading with constant amplitude of loading force, stress ratio R = 0.05 and frequency from 3 up to 8 Hz. The tests were performed at room temperature and ambient laboratory conditions in compliancy with EN 6072 [4], ASTM E 466 [5] and MMPDS-07 [6] specifications. Tests were conducted using standard uniaxial hydraulic test machines INOVA ZUZ 100 with load cell capacity of 100 kN and MTS 250 with 250 kN load cell. The maximum stress values σ_{max} were defined based on the nominal dimensions of the specimen's middle sheet.

Tab. 1 Configurations of individual test specimen batches

Rivet type	Strap sheets			Middle sheet		Note	E_f (GPa)
	t_1 (mm)	t_3 (mm)	Material	t_2 (mm)	Material		
5DuK 3x7P	0.8	0.8	D16čA TV	1.5	D16čA TV	*Round head (RH) solid rivet*	70
CR3213-4-02-T1						*CherryMax 3 (D=3.2 mm)*	210
CR4173-4-02-T1						*CherryMax 4 (D=3.175 mm)*	70
5DuPk 3x7P						*RH solid rivet + compensator*	70
5DuZz 3x7P						*CSH solid rivet + compensator*	70

Note- E_f-Young's modulus of a rivet

Results

The strain vs force measurement was conducted up to estimated load levels corresponding to 100 000 cycles until failure. The strain gauge measurements show a strong linearity of force vs. strain data. Fig. 3 illustrates the strain distribution through the specimen width for all measured specimens. Based on comparison of front vs back strain gauges (CherryMax4 specimen), an occurrence of approximately 5% bending can be observed. Moreover, the strain gauges indicate a slight non-uniform strain distribution through specimen width. The middle-positioned strain gauges show a slightly higher strain value as compared to the side strain gauges (about 3.5%).

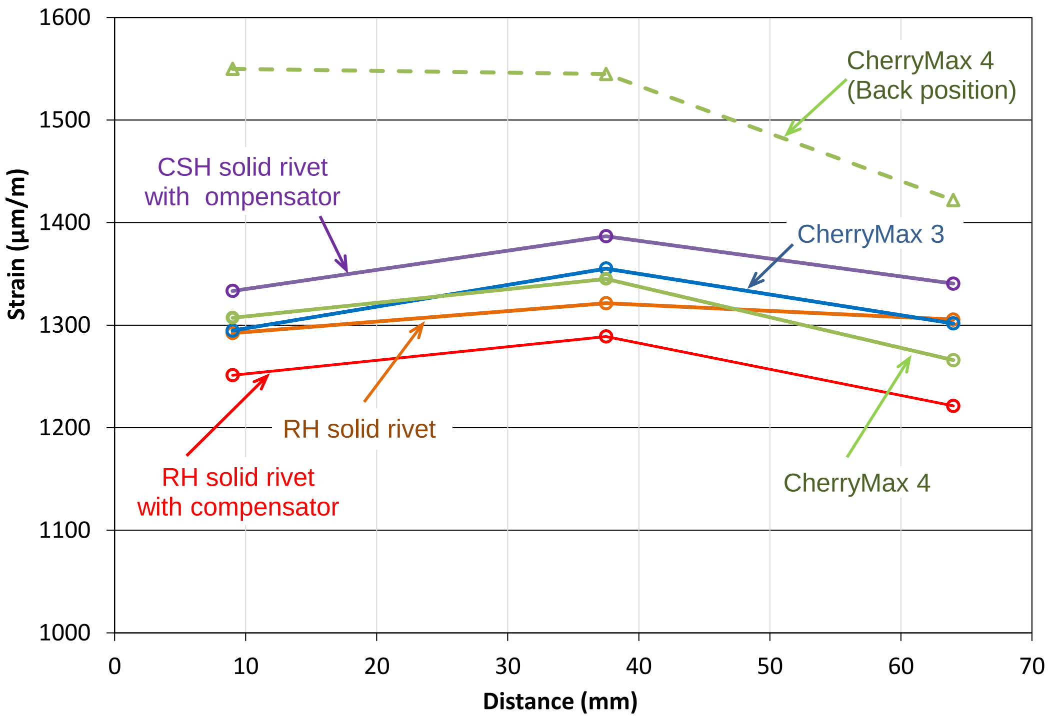

Fig. 3 Strain distribution through the width of specimens. Load level of 9.3 kN

Two main failure mode types were observed during the fatigue experiments:
1) Fracture of strap sheets 1 and 3 with a failure going through one rivet row, through two rivet rows or going through one rivet row and secondary crack initiation in different rivet row.
2) Fracture of the middle sheet with or without a crack initiation in the strap sheets. The fatigue crack initiation always started from the rivet holes.

An example of failure modes for one test specimen is shown in Fig. 4. Detailed views on failed joints with different failure mode are shown in Fig. 5.

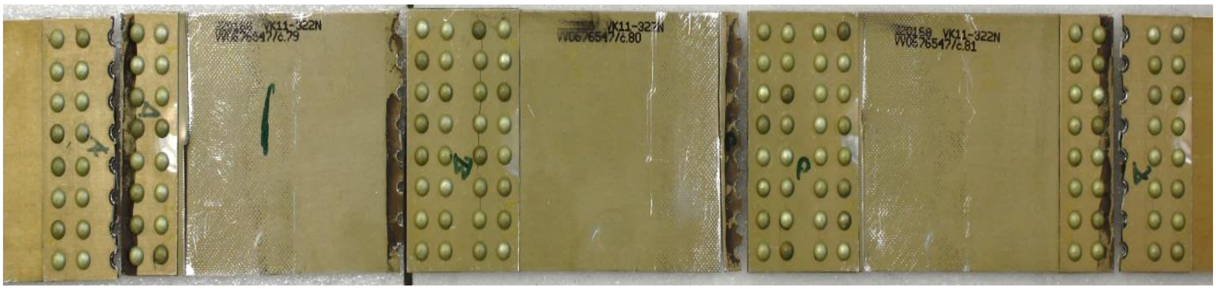

Fig. 4 Front side view of failed specimen, overall view

Fig. 5 Details of failed joints

The fatigue data from the each batch of specimens was evaluated using the linear regression by mean of a linear model in compliance with MMPDS-07 [6]. The linear regression model was represented by the equation:

$$\log(N_f) = A_1 + A_2 . log(\sigma_{max}), \tag{1}$$

where A_1 and A_2 are the regression constants, σ_{max} is the maximal stress level of the load cycle.

Fig. 6 shows linear regression curves for all test specimen batches. Significant fatigue strength differences were observed between individual batches differing in the rivet type. From viewpoint of the fatigue curves σ_{max} vs N_f evaluation, the longest fatigue lives were demonstrated for the 5DuPk 3x7P 1 – round head solid rivet with compensator.

Generally, the round head solid rivet types (with or without compensator) exhibit better fatigue behaviour as compared to other rivet types. The specimens with CherryMax 3 (D=3.2 mm) rivets, CherryMax 4 (D=3.175 mm) rivets, and the countersunk head solid rivets with compensator showed nearly one order shorter fatigue lives as compared to the test specimen with the round head solid rivet with compensator.

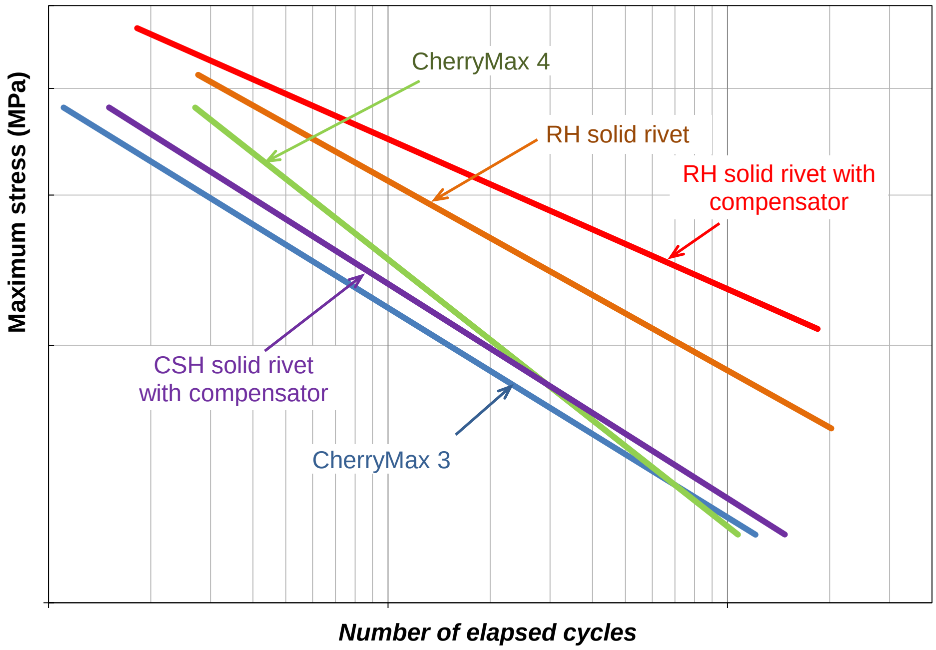

Fig. 6 Comparison of linear regression models for various mechanical double shear joints of D16č ATV sheets

Conclusions

The main goal of the fatigue tests was to determine the fatigue curves of the double strap butt rivet joints. Five batches of test specimens with different rivets were tested and evaluated. To clarify the fatigue data trends, a linear regression model was used. The best fatigue performance was showed in case of the specimens with round head solid rivet with and without compensator. For other test specimens types (CherryMax3 rivets, CherryMax4 rivets and countersunk head solid rivets with compensator), the fatigue lives were achieved nearly in one order shorter.

An additional bending moment was found in the middle part of the sheet although the double shear joints are symmetric. Approximately 5% bending was measured and a slight non-uniform strain distribution through the specimen's width (about 3.5%). The results were used as a base for inputs into numerical predictions of riveted structures used in a commuter aircraft.

Acknowledgement

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