SELECTION OF JOINTS FOR TESTING A FATIGUE LIFE OF AVIATION RIVETS

Dobór połączeń do badania trwałości zmęczeniowej nitów lotniczych

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Abstract: During the operation of aircraft, rivets sometimes loosen, what requires their replacement. The use of original rivets in repairs is troublesome and sometimes impossible due to the lack of access to the interior of the airframe structure. In this case, blind rivets should be used, provided that they have greater or equivalent strength to the original rivets. The aim of the study was to compare the statistical strength and fatigue life of the rivets that are usually used in the construction of the Mi-24 airframe and blind rivets that can be their substitutes. The object of the study included one-sided rivets: titanium core threaded MBF2110AB-05-15 with round head (4.2 mm diameter) and one-side Huck rivet with an extruded core (diameter 4.8 mm). The properties of these rivets were compared with those of ordinary 3558A-4-10 mushroom rivets manufactured from the W65 alloy used in the construction and repair of Mi24 helicopters. Comparative tests of rivet shear strength, head and end pull-off strength and fatigue life were carried out. An important problem turned out to be the selection of such a sample for fatigue tests, so that rivets and not the plates connected with them were destroyed by fatigue. These requirements were met by single strap samples in which C profile was strap.
Keywords: rivet joints, blind rivets, equivalent strength, fatigue strength

Streszczenie: W trakcie eksploatacji statków powietrznych dochodzi czasami do obluzowania nitów, co wymaga ich wymiany. Stosowanie w naprawach oryginalnych nitów jest kłopotliwe, a czasami niemożliwe ze względu na brak dostępu do wnętrza struktury płatowca. W tym wypadku należy zastosowań nity jednostronne pod warunkiem, że będą one miały większą lub równoważną wytrzymałość z nitami oryginalnymi. Celem prowadzonych badań było porównanie wytrzymałości statycznej i trwałości zmęczeniowej nitów zwykłych stosowanych w budowie płatowca Mi-24 oraz nitów jednostronnych mogących być ich zamiennikami. Obiektem badań były nity jednostronne: tytanowe, rdzeniowe nawlekane MBF2110AB-05-15 z łbem okrągłym (średnic 4,2 mm) jednostronne Hucka z rdzeniem wyciąganym (średnica 4,8 mm). Właściwości tych nitów porównywano z właściwościami nitów zwykłych grzybkowych 3558A-4-10 wytwarzanych ze stopu W65, stosowanych w budowie i naprawach śmigłowców Mi24. Przeprowadzono badania porównawcze wytrzymałości nitów na ścinanie, wytrzymałości na odrywanie łbów i zakuwek oraz trwałości zmęczeniowej. Istotnym problemem okazał się dobór takiej próbki do badań zmęczeniowych, aby zniszczeniu zmęczeniowemu ulegały nity, a nie łączone nimi blachy. Wymagania te spełniły próbki jednonakładkowe, w których nakładką był ceownik.
Słowa kluczowe: połączenia nitowe, nity jednostronne, równoważna wytrzymałość, wytrzymałość zmęczeniowa

Introduction

Airframe structures of aircraft are joined mainly by cold riveting methods due to the materials from which they are made, that is, from aluminum alloys of the AW 2xxx group [7, 8]. The production process mainly uses ordinary rivets made of aluminum alloys (e.g. Polish PA25 or Russian alloy W 65 with shear strength Rt = 245 MPa) with various types of heads. In heavily loaded connection nodes, so-called rivets with increased shear strength made of 30GHSA steel or titanium are use, which are essentially fitted pins. Blind rivets (one-sided) are also occasionally used in places where there is no access to the hold-on (bolster) in the riveting process [2].

During aircraft operation, rivets are sometimes loosened, what requires replacement, as tightening loose rivets is generally unacceptable, and damage to the skin, which requires the installation of the patches connected to the airframe structure by riveting. The use of original rivets in repairs is troublesome and sometimes impossible due to the lack of an access to the interior of the airframe structure. In this case, blind rivets should be used, provided they have equivalent or greater strength with the original rivets. Various blind rivets are available on the market, but most of them do not even meet the criterion of equivalent static shear strength. Considering the operational loads of helicopter airframes, besides short-term strength, fatigue strength of rivets and joints made with their use is equally important and even more important [5].

The latest blind rivets produced for aviation are stranded core rivets made of titanium alloys or steel. Due to the materials they are made of, they should be more durable than ordinary duralumin rivets. However, the admission of such rivets for the repair of military aircraft requires evidence that they will meet the requirement of equivalent strength and durability, which shall mean:

- not less static strength,
- no lower fatigue life of rivets,
- no less fatigue durability of joints made with these rivets,
- corrosion resistance, especially electrolytic.

The purpose of the research was to compare the static strength and fatigue life of ordinary rivets used in the construction of the Mi-24 airframe and blind rivets that could be their substitutes.

The objects of the study were blind rivets:

- titanium threaded core MBF2110AB-05-15 with round head (diameter 4.2 mm)
- one-sided Huck rivets with pull-out core (diameter 4.8 mm)

The properties of these rivets were compared with those of ordinary 3558A-4-10 mushroom rivets manufactured from the W65 alloy used in the construction and repair of Mi-24 helicopters. The strength of riveted joints has been devoted to many publications, whose comprehensive review and analysis are contained in [6]. In the research presented in this article, the main attention was devoted to the fatigue strength of the rivets themselves.

Static testing

Five single-overlap riveted samples were made witch use: standard rivets 3558A-4-10 and blind rivets MBF2110AB-05-15, as well as 5 single strap samples connected with Huck rivets. Single-overlap samples were created by connecting cuboid elements with dimensions 100x25x2 mm with two rivets. Single-overlap and single strap connections are made of plated AW 2024T3 alloy. The length of the connection overlap was 32 mm and the assumed rivet spacing corresponded to the assembly scheme of 10-12-10 mm. Plain rivets were pressed up in the press.

Single strap samples with Huck rivets were prepared with a 4 mm thick strap (80x25x4 mm) combining it with four rivets with 100x25x2 mm elements. The diagram of the connections used is presented in Fig. 1.

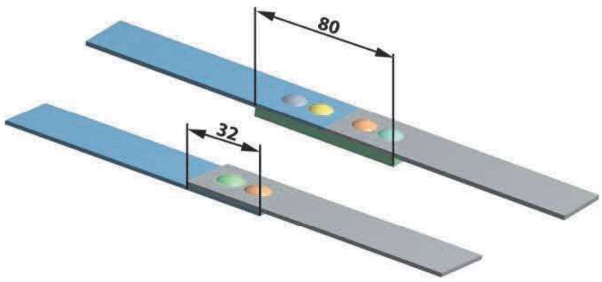

Fig. 1. View of the single-overlap and single strap samples

Strength tests were carried out on the ZD10 testing machine and the values of destructive forces for single-overlap and single strap joints are presented in Table 1.

Table 1. Load capacity of single-overlap and single strap joints [N] and rivets shear strength

Sample number	3558A-4-10 ordinary rivets	MBF2110AB-05-15	Huck rivets (single strap joint)
1	7350	11600	9500
2	7500	11700	9700
3	7500	11600	9700
4	7500	11400	9600
5	7350	11700	9500
Arithmetic average	7440±102	11600±151	9600±124
Shear strength of rivet	R_t = 296 MPa	R_t > 419 MPa	R_t = 265,4 MPa

Destruction of joints connected with plain and Huck rivets consisted of cutting the rivets (Fig. 2A), and joints connected with blind rivets by tearing off the heads, ovalization of the holes and plastic bending of the joined elements (Fig. 2B).

In the tests of static strength of connections with Huck rivets, a load capacity was obtained, which corresponds to shear strength Rt = 265.4 N, i.e. it is comparable with standard 3558A-4-10 rivets.

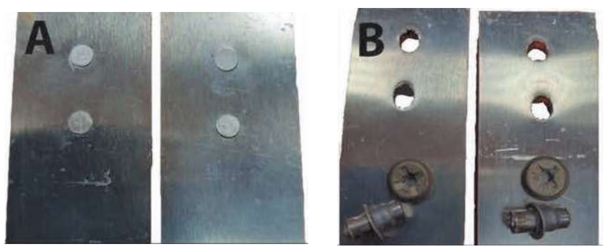

Fig. 2. Destruction of standard and blind rivets in the static strength test

Because the blind rivets have a different head and end cap structure than ordinary rivets, the tensile strength of the head and end rivets has been tested. The method used was based on riveting two C-profiles with an appropriate wall thickness (Fig. 3) and then loading them in a testing machine with the use of supports and a load transmitting element.

Fig. 3. Sample for testing the tensile strength of rivet heads

Five strength tests of the ordinary rivets were carried out, obtaining similar strength results: 5700, 5250, 5400, 5450 and 5300 N (average value of breaking force 5420 ± 218 N). Destruction of the rivet consisted not in breaking off the head, but in cutting it off (Fig. 4).

Fig. 4. Mechanism of rivet head destruction

In the case of MBF2110AB-05-15 blind rivets, the destruction consisted of breaking the threaded shank (Fig. 5) at 6900, 6800 and 6800 N.

Fig. 5. Destruction of the MBF2110AB-05-15 rivet in a pull-off test

The destruction of Huck rivets occurred at 2300 and 2250 N and consisted in breaking the sleeve connected to the head (Fig. 6).

Fig. 6. Destruction of Huck rivet in an attempt to detach the head

Due to the low head tensile strength, Huck rivets have been eliminated from further testing.

Fatigue tests

Selection of sample for testing fatigue life of rivets

The use of single-overlap samples in fatigue tests results in determining the fatigue life of the joint, not the rivets, because the joined sheets are damaged due to fatigue bending (Fig. 7) [8].

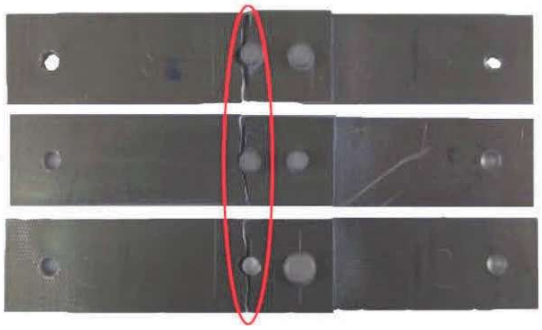

Fig. 7. Fatigue destruction of riveted single-overlap samples [1]

In order to eliminate bending, the suitability of double-overlap sample (Fig. 8) connected with one rivet was tested for fatigue testing.

Fig. 8. Double-overlap sample

Double-lap samples (with an overlap length of 20) connected with one rivet were prepared again from cuboid elements with dimensions of 100x25x2 mm and subjected to fatigue tests with a frequency of 20 Hz. Literature data shows that for load frequencies of 0.15 Hz and 40 Hz, the test results do not show differences regarding fatigue life of samples made of 2024-T3 alloy [5, 6]. Also, tests conducted on a three-row rivet joint made of 2024-T3 material at two different load frequencies 1 Hz and 10 Hz confirmed the lack of the test frequency on fatigue life of riveted joints [4].

In order to obtain rivet destruction with a number of cycles less than 500,000 cycles, the experimental tests changed the load range successively, increasing the average value of amplitude in the cycle. For the 1st range, extreme load values were equal to Fmax = 4500 N and Fmin = 3500 N, for the 2nd 5000 and 4000 N respectively, for the 3rd 5400 and 4000 N and for the 4th 6000 and 4000 N.

At the largest load range, the sample was destroyed after 89 238 cycles, but not the rivet, but the central plate. To reduce the stress in the joined elements in the next sample, 32 mm wide sheets were used. The sample was subjected to fatigue loading in the range of Fmax = 6000 N and Fmin = 4000 N. After 91.568 cycles, as in the case of a 20 mm wide sample, the central plate cracked. The shape of the crack and the deformation of the sheet (Fig. 9) show that the reason for such damage was exceeding the allowable pressures, whose value was: 731.7 MPa.

Fig. 9. Fatigue cracking of the central sheet of a double-overlap 32 mm wide sample

In order to eliminate the problem of excessive surface pressure, it was decided to use a larger number of rivets and a single strap asymmetrical connection (Fig. 10), in which shear stresses in the rivet shank are similar to those in a double-overlap sample with one rivet, and the surface pressures were twice as low. Such a sample also better reproduces the work of a skin supported on a longitudinal half-shell structure.

Fig. 10. Asymmetrical single strap sample

The sample was subjected to fatigue loading in the IV range, i.e. Fmax = 6000 N and Fmin = 4000 N. After 260 812 cycles, the strap fatigue cracked (Fig. 11). Therefore, it was decided to replace the flat strap with a 25x15x2 mm dural channel bar (Fig. 12) in order to cause fatigue damage of the rivets.

Fig. 11. Fatigue crack of flat cover plate

Fig. 12. Single strap sample with C-profile

The sample was subjected to fatigue in the range of Fmax = 6000 N and Fmin = 4000 N. After 819,000 cycles, the load Fmax = 6600 N and Fmin = 4000 N was increased and the sample was subjected to further testing. After completing an additional 37,610 cycles, the rivets on one side of the strap were damaged (Fig. 13).

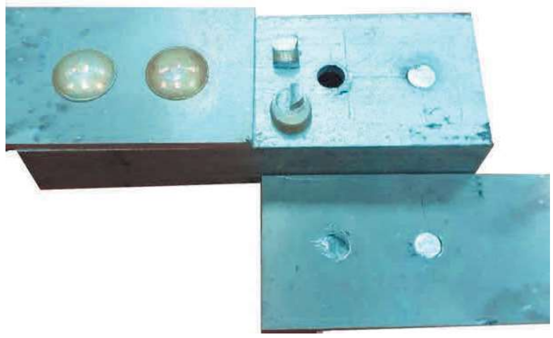

Fig. 13. Nature of fatigue failure of rivets of a single-strap sample with C-profile

The next single-strap sample with C-profile was subjected to fatigue loading in the range of Fmax = 6600 N and Fmin = 4000 N. After 391, 785 fatigue cycles, fatigue cutting of the rivets occurred (Fig. 14).

Fig. 14. The nature of fatigue failure of a single-strap sample with C-profile loaded in the range Fmax = 6600 N and Fmin = 4000 N

The conducted tests allowed accepting the conditions of comparative fatigue tests of ordinary rivets and their blind rivet substitutes. In order to obtain the destruction of the rivets, and not the joined sheets, it was decided to use single-strap samples in which the strap will be a C-profile. It was decided to load the samples in the same range Fmax = 6600 N and Fmin = 4000 N with a frequency of 20 Hz, and the tests lead to at least 500,000 load cycles.

A single-strap sample with C-profile connected with round head MBF2110AB-05-15 titanium rivets had fatigue life of 610,000 cycles and the test was discontinued. Computed tomography (Fig. 15) tests showed that in the sample with round head MBF2110AB-05-15 titanium rivets, loose connection, decalibration of holes and displacement of the connected elements.

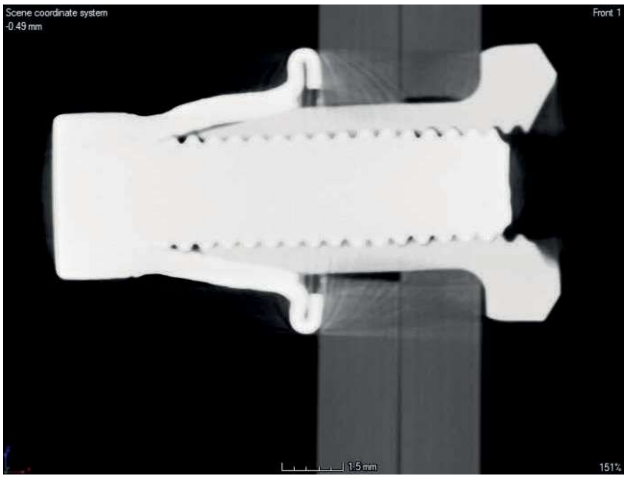

Fig. 15. Sample with MBF2110AB-05-15 titanium rivets after 610,000 load cycles

Conclusions

The tested blind rivets MBF2110AB-05-15 have higher shear strength compared to the rivets to be replaced with them, and Huck rivets about 10% lower. The latter, due to the low head pull-off strength, cannot be substitutes for the ordinary rivets.

Preliminary tests allowed selecting a sample for comparative tests of fatigue life of ordinary rivets and strength-equivalent blind rivets - a single-strap sample with a strap in the form of a C-profile.

MBF2110AB-05-15 titanium blind rivets with round head are also characterized by greater fatigue life compared to standard 3558A-4-10 rivets.

Comparative fatigue tests should be carried out to check how blind rivets affect the fatigue life of the sheets to be joined. Such tests can be carried out on single-overlap samples.

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