LOAD CAPACITY AND FATIGUE LIFE OF HYBRID JOINTS

Nośność i trwałość zmęczeniowa połączeń hybrydowych

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A b s t r a c t: The paper presents the results of experimental research the aim of which was to compare the load capacity and fatigue life of single-lap joints of 2024-T3 aluminium alloy elements. The test specimens have been connected with adhesive bonding, mechanical fastening as well as by means of hybrid joints (adhesive and screw joints). Specimens with 25 and 50 mm overlaps have been used in the tests and geometry of joints has been modified by changing the mechanical fasteners location; mounted at 2 and 1 fastener hole diameter distance from overlap edge. It has been found that the use of mechanical fasteners in hybrid joints is effective only if appropriate overlap length is used. What is more, it has been empirically proven that the installation of mechanical fasteners in hybrid joints that are closer to the end of the overlap edge (less than the minimum recommended distance for mechanical joints) is justified taking into account the load capacity and fatigue life.
Keywords: hybrid joints, load capacity of joints, fatigue life of hybrid joints

S t r e s z c z e n i e: W pracy zaprezentowano rezultaty badań własnych, których celem było porównanie nośności i trwałości zmęczeniowej połączeń jednozakładowych, w których łączono elementy wykonane ze stopu aluminium 2024-T3. Próbki do badań łączono klejem, śrubami oraz w sposób hybrydowy (klejowo-śrubowy). W badaniach zastosowano próbki z zakładkami o długości 25 i 50 mm oraz z łącznikami mechanicznymi montowanymi w odległości równej dwóm i jednej średnicy śruby. Stwierdzono, że zastosowanie łączników mechanicznych w połączeniach hybrydowych jest efektywne pod warunkiem zastosowania odpowiedniej długości zakładki. Udowodniono eksperymentalnie, że w połączeniach hybrydowych montaż łączników bliżej końca krawędzi zakładki (poniżej min. odległości zalecanej dla połączeń mechanicznych) jest uzasadniony biorąc pod uwagę kryterium nośności połączeń i ich trwałości zmęczeniowej.
Słowa kluczowe: połączenia hybrydowe, nośność połączeń, trwałość zmęczeniowa połączeń hybrydowych.

Introduction

Hybrid joints as a combination of adhesive and screw connections is an interesting alternative to joining elements made of both metal and composite materials. Research papers on hybrid connections show that they exhibit better strength parameters compared to mechanical or adhesive joints both in static and durability range [4, 7, 8]. As the authors of the paper [3] indicate, the reason for their greater fatigue durability are smaller stress concentrations in the vicinity of the holes.

Hybrid connections are also considered as joints for which it is much easier to carry out the certification process in air constructions compared to adhesive connections [2]. Their application is recommended by the FAA (Federal Aviation Administration). The use of hybrid connections can also mean using a smaller number of mechanical fasteners in the assembly node [2, 9].

In aeronautical constructions, where thin-wall elements are connected, the use of adhesive joints is more effective, however this type of joints is characterized by limited efficiency in transferring complex load conditions causing "tearing off" at the ends of the adhesive joint [5, 6]. Hence, the simultaneous use of mechanical fasteners with adhesive joints at the ends of adhesive overlaps should significantly improve the resistance of hybrid joints to this type of load cases. An important problem in the effective use of hybrid joints is such construction of the connection node, in which the optimal division of loads between mechanical and adhesive connections occurs [1].

The aim of the experimental tests was to compare the load capacity and fatigue life of adhesive, mechanical and hybrid joints in single-lap connections of two different lap lengths. The quantitative influence of a change in the distance between the installation and the edge of the mechanical fasteners overlap with the tested parameters was also analysed. In this way, it was assessed whether the installation of fasteners closer to the edge of the overlap produces positive effects in terms of load capacity and fatigue life of joints.

Research methodology

In experimental studies, single-lap joints were used in which elements made of aluminium alloy, series 2024-T3, were connected in an adhesive, mechanical and hybrid manner. The jointed elements were sheets 100 mm long, 25 mm wide and 2 mm thick. Epidian 57/Z1 adhesive (mixed in 10: 1 mass proportions) was used to prepare adhesion and hybrid joints. Pressure during curing of adhesive joints was equal to 0.96 MPa. The adhesive layer was hardened in two stages, i.e. 24 hours at 20 °C and 8 hours at 80 °C. For the preparation of mechanical and hybrid joints, fasteners in the form of steel screws: series 8.8, with a diameter of ø 3mm BN-73/1112-03 were used. The lengths of the threaded bolt parts are selected so that no thread cuts are present in the mounting holes. The surfaces of the elements for bonding were prepared by degreasing them with acetone, sandblasting with an electrocorundum with a grain diameter of F40 and air pressure of 8 atmospheres and re-washing with acetone. When, in the course of conducting endurance tests, it turned out that the sandblasting of the surface of the elements to be bonded has a negative impact on the fatigue life of the joints, the sandblasting in hybrid joints was replaced by roughening with abrasive paper with a grain of P80 (abrasive grain size from 180 to 212 μm). The screws were installed halfway through the width of the specimen in three different configurations of the fastener's distance from the edge of the overlap. The distance was measured by the diameter of the holes for mechanical fasteners - hence the 2 or 1 hole diameter (2D, 1D) was assumed for the needs of this research paper. The bolts were mounted with a torque of 2.2 Nm. In the case of hybrid joints, the bolts were assembled before the adhesive hardened. In order to obtain a uniform thickness of the adhesive layer, spacer threads were used in both adhesive and hybrid joints. Specimens with two following tab lengths were tested: 25 and 50 mm. The specimens were subjected to statical and fatigue loading with a ZD-10 testing machine with a pulsator. Fatigue life test was carried out in the range of cycle loads: 1.5 - 4.5 kN (average cycle load 3 kN) with a frequency of 8 Hz and cycle asymmetry factor of R = 0.33. The hybrid joint scheme used in the research is presented in Fig.1.

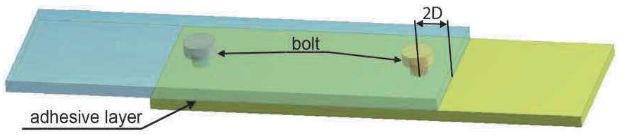

Fig. 1. Scheme of screw and adhesive joint prepared for the needs of the research
Rys. 1. Schemat połączenia śrubowo – klejowego przygotowanego do badań

In the first stage of the research, the load capacity and fatigue life of adhesive, mechanical and hybrid joints with an overlap length of 25 mm were compared.

In the second stage, joint strength and fatigue life were also compared, however the length of the overlap was increased to 50 mm. Moreover, at this stage, the distance between installation of the mechanical fasteners and the edge of the overlap was also changed, assessing the impact of such modifications on the load capacity and fatigue life of the joints.

In order to determine the load capacity of joints, the tests were carried out for five samples, while fatigue life, due to the duration of tests, was determined for three or four samples.

Results

The results obtained in empirical research for the first stage are presented in Fig. 2 and in Table 1.

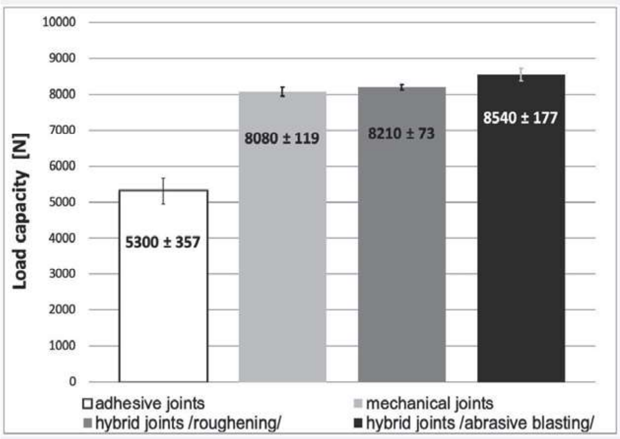

Fig. 2. Comparison of load-bearing capacity of adhesive, mechanical and hybrid joints (for two variants of surface preparation)
Rys. 2. Porównanie nośności połączeń adhezyjnych, mechanicznych i hybrydowych (dla dwóch wariantów przygotowania powierzchni)

Table 1. Fatigue life of joints with 25 mm overlap and fasteners installed at 2D distance from overlap edge
Tabela 1. Trwałość zmęczeniowa połączeń o zakładce 25 mm, montaż łączników mechanicznych w odległości 2D od krawędzi zakładki

Fatigue life [number of cycles]			
No.	Adhesive joints	Mechanical joints	Roughened hybrid joints
1	120	80100	135200
2	300	155900	145000
3	50	143200	165550
Mean	157	126400	148583

The average load capacity of mechanical joints compared to the adhesive ones was higher by more than 50%. In hybrid joints with roughened elements, there was practically no increase in the load capacity of joints compared to mechanical joints, while slightly higher load values were recorded for hybrid joints with sandblasted elements, which is associated with higher adhesion strength of the adhesive joint due to surface sandblasting.

In terms of fatigue life, there was a big difference between the durability of adhesive joints and the durability of other connections. The very low fatigue life of adhesive joints can be explained by the high value of the maximum cycle load - 4.5 kN - this is the value that corresponds to almost 85% of the average load capacity of this type of joints. The highest fatigue life was characterized by hybrid joints with non-sandblasted elements, in contrast to the durability of hybrid joints, but with sandblasted elements. Their durability was even lower than the fatigue life of mechanical joints - although their load capacity was the highest among all tested joints in this series. The decrease in fatigue life of joints with sandblasted elements should be explained by the very negative influence of small structural notches that are formed on the sandblasted surface. In this case, even the presence of an adhesive layer did not eliminate this negative phenomenon.

The results obtained in experimental research for the second stage are presented in Fig. 3 and in Table 2.

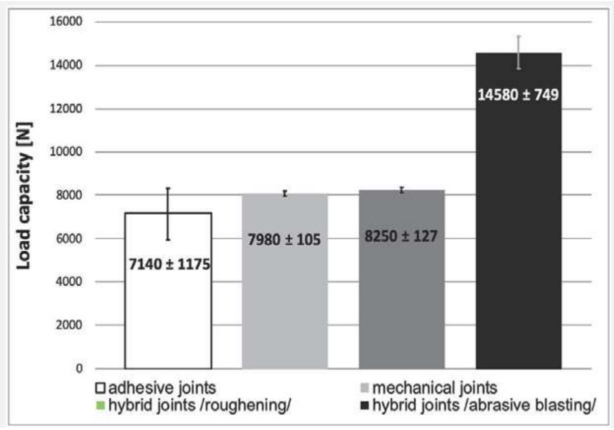

Fig. 3. Comparison of load-bearing capacity of adhesive, mechanical and hybrid joints (for two variants of surface preparation)
Rys. 3. Porównanie nośności połączeń adhezyjnych, mechanicznych i hybrydowych (dla dwóch wariantów przygotowania powierzchni).

Table 2. Fatigue life of joints with 50 mm overlap and fasteners installed at 2D distance from overlap edge
Tabela 2. Trwałość zmęczeniowa połączeń o zakładce 50 mm, montaż łączników w odległości 2D

Fatigue life [number of cycles]			
No.	Adhesive joints	Mechanical joints	Roughened hybrid joints
1	7000	141550	1059750
2	9500	89300	1260500
3	4300	166800	1015400
4	12000	179200	1098500
Mean	8200	162517	1108538

The double increase of the connection overlap area resulted in an increase in the load-bearing capacity of adhesive joints by approx. 35%, while the load-bearing capacity of the mechanical connections practically remained unchanged. The influence of the surface preparation method on the load capacity of hybrid joints was noticeable for such a length of overlap – joints with sandblasted elements were characterized by an increase in load capacity by 83% compared to mechanical joints, whereas for joints with non-sandblasted elements, the increase was unnoticeable. The load-bearing capacity of adhesive joints and mechanical joints was not much different, much less than for joints with a 25 mm overlap.

Increasing the length of the overlap positively affected the fatigue life of all types of joints, which should be explained by the greater stiffness of joints and, therefore, their lower susceptibility to secondary bending moments. Surprising results were obtained for hybrid joints with non-sanded elements, in which there was a 7.5-fold increase in fatigue life – despite the fact that their load capacity was significantly lower than hybrid joints with sandblasted elements. Once again, the low practical application of sandblasting as a method of surface preparation for bonding in the context of use of future joints under variable load conditions was proven. In the case of sandblasted hybrid joints, along with increasing the length of the overlap, a proportional increase in fatigue life was achieved (a double increase in the area of the adhesive bonding surface). Due to the very negative impact of sandblasting on the fatigue life of hybrid connections, in the next stage of the research, it was decided to abandon the sandblasting of components for the preparation of hybrid specimens. The results of load capacity and fatigue life obtained after modification of mechanical and hybrid joints consisting in installation of bolts closer to the edge of the overlap (distance 1D) are presented in Fig. 4 and Table 3.

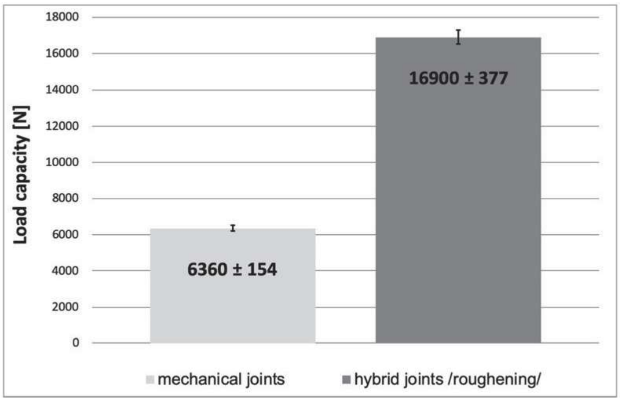

Fig. 4. Comparison of load-bearing capacity of mechanical and hybrid joints with 50 mm overlap, installation of fasteners at 1D distance from the overlap edge
Rys. 4. Porównanie nośności połączeń mechanicznych i hybrydowych o zakładce 50 mm, montaż łączników w odległości 1D

Table 3. Fatigue life of joints with 50 mm overlap, fasteners installed at 1D distance from the overlap edge; (* - test samples were not damaged)
Tabela 3. Trwałość zmęczeniowa połączeń o zakładce 50 mm, montaż łączników w odległości 1D; (* - próbki nie uległy zniszczeniu)

Fatigue life [numbers of cycles]	
No.	Mechanical joints
1	472600
2	281600
3	450500
4	NDA
Mean	401567

After modifying the installation of fasteners, the load capacity of the mechanical joints dropped by about 20%, but because there was another mechanism in the tests to damage the joint, the bolts were not sheared and the joints were damaged as a result of exceeding the permissible stress on surface pressures in the bolt holes. In the case of hybrid joints after modification, more than two-fold increase in the load capacity was observed, which even exceeded the capacity of hybrid joints with sandblasted elements and bolts installed at 2D distance.

Modification of the installation of the fastener closer to the edge of the overlap turned out to be a beneficial procedure in terms of their fatigue life. In mechanical joints with a 50 mm overlap, the increase of an average fatigue life doubled. Due to the small distance of the wall of the hole from the edge of the joined elements, there was also another form of fatigue damage. Samples No. 1 and 3 of the mechanical joints were damaged not in the critical section, but at the edge of the overlap. Hybrid specimens No. 1 and No. 4 were not damaged during the tests. In sample No. 3 of the hybrid joints, after the tests, defects were found at the ends of the overlap. Modification of the fastener installation in the case of hybrid joints had a significant impact on increasing their fatigue life. In the case of two samples, at least a 25-fold increase in the fatigue life of joints was noted ("at least", because the analysed joints were not damaged).

Conclusions

Based on the performed experimental tests, it was found that:

- execution of hybrid joints using sandblasting with the above parameters as a method of surface preparation for bonding has a negative impact on their fatigue life.
- the use of mechanical fasteners in a hybrid joints is effective provided that appropriate length of the overlap (in the author's own research it was 50 mm) or the appropriate area of the bonded surface is applied.
- otherwise, there is no effective division of the load between the adhesive joint and mechanical fasteners.
- in hybrid joints, the position of the mechanical fastener at a distance equal to 1 bolt hole diameter from the edge of the overlap (in mechanical joints the recommended distance is equal to two diameters) is justified. In static and fatigue tests, it has been proven that this solution increased both the load-bearing capacity and fatigue life of joints. Nevertheless, in the case of mechanical joints alone, reducing this distance is the wrong solution – the fatigue life of the joints is reduced.

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