ISSN 1648-7788 AVIATION, Vol IX, No 2, 2005
PROCEEDINGS OF THE SIXTH INTERNATIONAL SEMINAR ON
"Recent Research and Design Progress in Aeronautical Engineering and its Influence on Education" – Riga, Latvia

INFLUENCE OF AGEING ON RIVET-BONDED JOINT PROPERTIES

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Abstract. Riveting and adhesive bonding are common joining technology in aircraft engineering. A hybrid joining such as rivet-bonding brings together the benefits of both basic techniques whilst minimising some of their shortcomings. These technologies have been present mastered sufficiently, and their characteristics are well known. Due to different influences in aircraft service (weather, location of aircraft operation, air composition, contact with fuel or hydraulic fluid), a degradation of the characteristics of joints is well noticed. This research was focused on the ageing of rivet-bonded joints with a polyurethane adhesive and blind rivets and the influence of ageing on the properties of joints. Ageing according EN 2243-5 was carried out in hot/wet conditions, salt mist, hydraulic fluid, and fuel. Thermal cycling was used as a resource of ageing.

Keywords: rivet-bonding, ageing, shear strength, peel strength, joint stiffness.

Introduction

A combined rivet-bonded joint puts together advantages of both basic technologies and eliminates their drawbacks. Use of an adhesive can notably enhance the strength and stiffness of a joint so that the number of rivets can be reduced. It is also possible to use a smaller overlapping area. The adhesive has a positive influence on load distribution and lowers stress peaks caused by rivet holes. Rivets considerably improve joint peeling strengths. From an economic aspect, two simultaneous processes are used here, and that can result in an increased final price.

The use of adhesives in a combined joint depends on design philosophy. In most cases we deal with the following alternatives:

- Joints where adhesive operates as a seal component only. All load is transferred by the rivets.
- Bonded joints with technologic rivets as a source of assembly and curing pressure. All load is transferred by the adhesive.
- Combined joints where load transfer is shared proportionally by the rivets and the adhesive.

The adhesive also serves as an effective barrier to the corrosion process in the gaps between metal interfaces. Influence of climactic conditions on the corrosion of aluminium alloys is well known. Pure aluminium is a very reactive element, and it can oxidize very fast and easily. Although it is chemically reactive, we use its continuous surface oxidized layer to prevent further corrosion. Mechanical and chemical characteristics of this thin layer are generally dominant for practical use of aluminium alloys. The oxide layer, covered by one or more paint layers, can be considered as sufficient prevention of material corrosion. Some kinds of adhesives are quite resistant to acids and humidity. Generally in literature we can find that the strength of an adhesive exposed to a humid environment rises for a long time, but when it exceeds a defined limit, specific for the individual adhesive, the strength decreases very rapidly [1].

The adhesive also prevents the possible initiation of galvanic corrosion when we bond two different types of metal material. Concentration cell, or crevice corrosion, is the result of differences in the environment at a metal surface. It typically occurs in a crevice or stagnant area. A commonly encountered form is oxygen differential cell corrosion where the entrapped moisture in the crevice has the lower oxygen content than at the open surface. Additionally, when moisture and salt are present, chloride ions migrate to the oxygen-depleted zone (anode) inside the joint, creating an acidic and corrosive condition [2]. This feature is shown in Fig 1. The possible degradation of combined rivet-bonded joints can be caused by the corrosion process on the adhesive-metal interface and/or ageing of the adhesive Previous research focused on basic properties of hybrid joints with blind rivets and two types of adhesives – polyurethan and epoxy [3]. In the next sections, the influences of environment conditions on mechanical characteristic of hybrid joints will be explained.

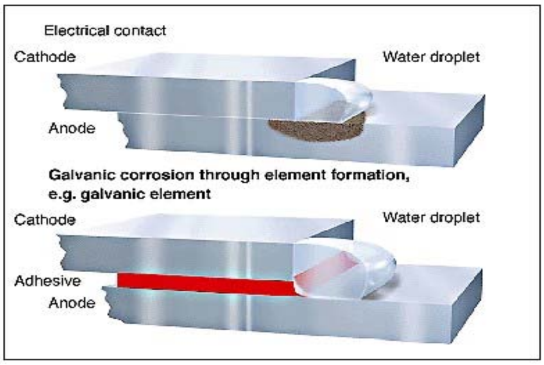

Fig 1. Sample of corrosion

2. Experimental program

Due to program settings, two kinds of specimens were manufactured in cooperation with the company EVEKTOR. The first was intended to verify peeling characteristics, and the second kind was a simple overlapped joint tested for strength and stiffness characteristics. Specimens were made of 2224-T4 aluminium alloy, with an ELOX 6 anodic oxidized surface layer and subsequently covered by the synthetic undercoat 2003/0660. The joint was made with the thixothropic polyurethane adhesive EMFI MASTIC PU-50 (Tab 1) in combination with two ⌀ 3.2 x 4.3 mm AGS 717402 blind rivets.

Table 1. Properties of PU-50 Emfi Mastic Adhesive

	PU-50
Characteristic	One-component polyurethane adhesive, hardering by moisture, tear resistance and good weatherproofing
Viscosity	Thixotropic paste
Storage life	9 months (5-25°C)
Throughput time	15 min (20°C)
Thermal stability	-40°C / +90°C
Shear strength	1.6 Mpa (23°C)
Elastic modulus	0.8 (ISO 37)
Fracture strain	80% (ISO 8339)
Hardening time	60 min. (23°C, 50% R.V.)
Hardness	50 Sh A (ISO 868)

This hybrid joining is a common method used in the manufacture of light aeroplanes at EVEKTOR. The dimensions of the specimens were as follows: 60 mm width, 40 mm overlap, and 0.8 mm sheet thickness. Various selected types of environmental conditions according to the standard EN 2243-5 (Structural adhesives. Test methods. Part 5: Ageing tests), in which specimens were exposed, are described in Tab 2. In addition to that, cyclic heating was used as a source of joint properties degradation.

The ageing of specimens was created in cooperation with the clime-technological laboratory of the Aeronautical Research and Test Institute in Prague – especially exposure to hot/wet conditions, salt mist, fuel, and cyclic heating. Tests with aircraft hydraulic fluid (AEROSHELL FLUID 41) were done in the technological laboratory of the Institute of Aerospace Engineering. Due to evaporation loss (12% / 71°C / 6 hrs), test was done in an autoclave.

Table 2. Ageing conditions

Environment	**Temperature**	**Time**
Relative humidity 95-100%	+70° C ± 3° C	10,20,30,days
Salt mist	+35° C ± 2° C	30,60 days
Aircraft hydraulic fluid	+70° C ± 3° C	15 and 30 days
Cyclic heating	-20° C / +50° C	100, 200, 400, 600 cycles
Natural 95 fuel	+40° C	30,60 days

2.1 Shear strength and stiffness of rivet-bonded joints

Shear strength of the rivet-bonded joint is given by ratio of the maximum force during the test and the bonded area relevant to one rivet. When an adhesive is applied, the shear strength increases with increased overlap. In this case we deal with an overlap of 40 mm p. Specimens were loaded on an Instron test machine until failure by 2 mm.min^{-1} drift velocity. An MFA 2 strain gauge (gauging length 50 mm, gauging range 2 mm) was used to get the correct deformation data. The average failure shear strength, standard deviation, and percentage difference comparised to the reference specimens are shown in Tab 3.

Table 3. Average shear strength of joint

Environment	Shear Strength [MPa]	Standard deviation	Percent difference (rounded off)
No environmental influence	4,11	-	0
Hot/wet (10 days)	4,15	0,42	+1
Hot/wet (20 days)	4,28	0,18	+4
Hot/wet (30 days)	3,74	0,26	-9
Salt mist (30 days)	3,87	0,27	-6
Salt mist (60 days)	3,75	0,17	-9
Hydraulic liquid (15 days)	4,18	0,389	+2
Hydraulic liquid (30 days)	4,04	0,22	-2
Cyclic heating (100 cycles)	4,02	0,18	-2
Cyclic heating (200 cycles)	4,07	0,173	-1
Cyclic heating (400 cycles)	4,25	0,54	+3
Cyclic heating (600 cycles)	3,8	0,2	-8
Fuel - Natural 95 (30 days)	4,046	0,109	+2
Fuel - Natural 95 (60 days)	4,087	0,212	+0,5

Fig 2 represents the graphical expression of shear strength values. The stiffness of the individual structural parts determines local stress distribution with the known influence on fatigue performance. The joints in aircraft structures are usually dynamically loaded and they are stabilized after the 5 - 10 % life cycle.

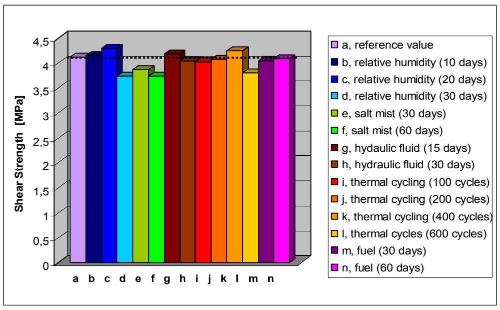

Fig 2. Shear strength of rivet-bonded joint

The static tensile test recommended by Huth as a method to replace the long life test was used to determinate joint stiffness [4]. The joint is unloaded after reaching 2/3 limit load F_{max} and then loaded again. Joint deformation is determined from the linear part of the second loading curve according to

$$\Delta l = \Delta l_{ext} - \frac{\Delta F.(L-l)}{w.t.E} \qquad (1)$$

where
- ΔF - load addition, N
- L - extensometer measuring length, mm
- E - sheet Young modulus, MPa
- t - sheet thickness, mm
- w - specimen width, mm
- l - joint overlap, mm
- Δl_{ext} - deformation measured by extensometer, mm
- Δl - joint deformation including rivet deformation, adhesive layer deformation and sheet elastic deformation, mm

The joint stiffness is then expressed as:

$$K = \frac{\Delta F}{\Delta l}, \quad \text{N.mm}^{-1} \qquad (2)$$

Joint stiffness, as in Fig 3 decreased 30% on average. An overview of decreasing magnitude is described in Tab 4. We can say that decreasing joint stiffness can have a serious negative effect on the entire construction (in our case, the structure of a light aircraft).

Table 4. Average stiffness of joint

Environment	Joint stiffness [N.mm^{-1}]	Standard deviation	Percent difference
No environmental influence	23713,3	-	0
Hot/wet (10 days)	18812,4	2353,6	-20
Hot/wet (20 days)	19464	1060,4	-18
Hot/wet (30 days)	16204,6	1504,9	-32
Salt mist (30 days)	15947,2	1862,6	-33
Salt mist (60 days)	17088,4	3081,9	-28
Hydraulic liquid (15 days)	17556	3730,98	-26
Hydraulic liquid (30 days)	17167,6	3265,55	-28
Cyclic heating (100 cycles)	15756	1384,9	-34
Cyclic heating (200 cycles)	14823,2	1665,36	-37
Cyclic heating (400 cycles)	15496,2	1044	-35
Cyclic heating (600 cycles)	14627,6	1248,63	-38
Fuel – Natural 95 (30 days)	19708,2	1277,98	-17
Fuel – Natural 95 (60 days)	19690,2	1901,26	-17

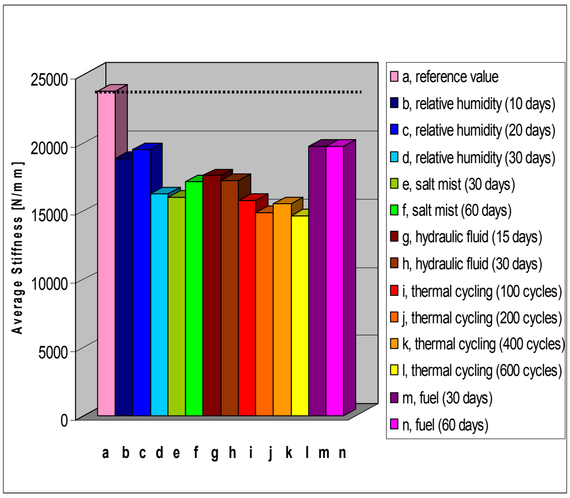

Fig 3. Stiffness of rivet-bonded joint

2.2 Peeling strength

Peeling strength is one of the most important characteristics of adhesives. To get a complete understanding of environmental influence to bonded joint, it is necessary to accomplish these tests. Two kinds of environmental conditions were selected: hot/wet conditions and a salt mist (Tab 2). These conditions have the greatest influence on the adhesive used. Adhesive bonded specimens were prepared according to the standard EN 2243-2 (Structural adhesives. Test methods. Part 2: Peel metal – metal). Dimensions of specimens are: 25mm in width and 200mm in bonded length. The test was carried out according EN 2243-2. The results are mentioned in Fig 4 and Tab 5. It is evident that the influence of hot/wet ageing is more pronounced than the influence of salt mist.

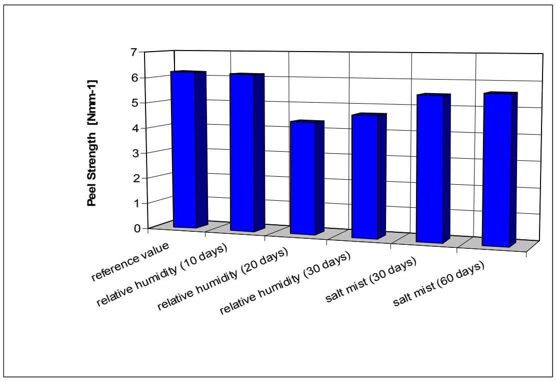

Fig 4. Peeling strength of adhesive bonded joints

Table 5. Peel strength of adhesive bonded joints

Environment	Peeling strength (N/mm)	Standard deviation	Percent difference
No environmental influence	6,2	6,2	6,2
Hot/wet (10 days)	6,15	6,15	6,15
Hot/wet (20 days)	4,35	4,35	4,35
Hot/wet (30 days)	4,69	4,69	4,69
Salt mist (30 days)	5,49	5,49	5,49
Salt mist (60 days)	5,59	5,59	5,59

3. Discussion

The shear strength of rivet-bonded joints was not noticeably been affected by exposing the environments. Measured values of exposed specimens reached similar valuations as reference specimens considering dispersion due to measuring and manufacture. In case of cyclic heating, the stiffness of joints decreased of 38%. Temperature cycling can, in connection with other effects, cause a decrease in joint stiffness in defined time range. Nevertheless, the stiffness values of aged joints stay higher that the stiffness of the joints that are riveted only – Fig 5.

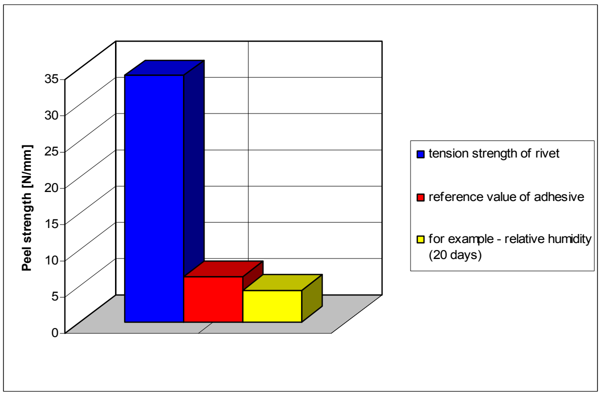

Fig 5. Peel strength of joints

There were two types of an adhesive layer rupture. Cohesive failure can be seen on the edges of the bonded area, and in the area near the rivets adhesive failure can be noticed. Also primer paint layer peeling exists in the middle area of the overlap. Similar types of failure were found in both series of specimens – reference and aged – Fig 6. Obviously the degradation of stiffness properties is more due to adhesive ageing than due to corrosion processes.

Fig 6. Example failure of adhesive layer

The peel strength had decreasing trend upon exposition to selected environments. Degradation reached 30%. The cause of this behaviour is described above.

Conclusions

In this work, the influence of the environment on the strength and stiffness of joints and on peeling strength are explained. The Positive effect of an adhesive decreases slightly after a definite time but a more significant influence of the environment can be seen on stiffness characteristics. Despite these results, the benefit of this type of joint appears as an important factor for increasing the mechanical characteristics of a joint.
The adhesive has not lost sealing ability after ageing.

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