FATIGUE BEHAVIOUR OF ADHESIVE BONDED ALUMINIUM ALLOYS CONNECTIONS

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Abstract : Preliminary results of a testing programme for the characterization of the fatigue behaviour of adhesive bonded connections of aluminium alloys are presented. The adhesives used were epoxy resins and the base materials were aluminium alloys of the 5xxx and 6xxx series.

The experimental programme consists on the determination of SN curves. The experimental data obtained was subjected to a statistical treatment and was compared with results for welded joints. It was found that it is possible to obtain adhesive connections with greater fatigue strength than equivalent welded connections.

1 - INTRODUCTION

Structural adhesive bonding is used extensively in the aerospace industry. Its application in other industries is less common and is now actively researched, mainly in the automotive and transport industries in general [1,2]. The main reasons for this interest are related to ease of fabrication, high joint strength - particularly under fatigue loading -, suitability to join dissimilar materials and reduced manufacturing costs.

Fatigue tests were conducted on bonded double butt joints in 5754 H32 and 6061 T6 aluminium alloy specimens. Two types of epoxy structural adhesives (A and B) were used.

The fatigue strength of a bonded joint depends on several parameters, such as the mechanical properties of the adhesive and of the base material, the surface treatment of the base material, the thickness of the adhesive, joint geometry, stress state and environment. The effect of environment (air and humid conditions) in the fatigue behaviour was studied (although at the date of this report data for humid conditions is not yet completed).

The specimens of 5754 H32 aluminium alloy were tested in air at ambient temperature.

The specimens of 6061 T6 aluminium alloy were tested under humid conditions; the specimens were soaked for 5 days before testing.

The fatigue behaviour of the bonded joints was evaluated using 3 stress levels.

The results obtained are compared with data obtained in tests with welded joints carried out within the EUREKA EU 269 project and reported in ref.[3].

2 - EXPERIMENTAL PROCEDURE

2.1 - Fatigue testing in air

Epoxy adhesives were used. The shear strength was 28 MPa for the adhesive A and 40 MPa for the adhesive B.

Tests in air were carried out with 5754 H32 aluminium alloy specimens. Ultimate tensile strength and yield strength of 5754 H32 aluminium alloy are 220 and 140 MPa respectively. The specimen geometry is illustrated in Figure 1. Overlap length was l=40 mm for the adhesive A and l=20 mm for the adhesive B. The thickness of the base material was 6mm, and the adhesive thickness was approximately 0.3 mm.

The base material was subjected to a degreasing pretreatment, in the case of the specimens bonded with adhesive B; degreasing, etching and chromate based conversion, were used in specimens bonded with adhesive A.

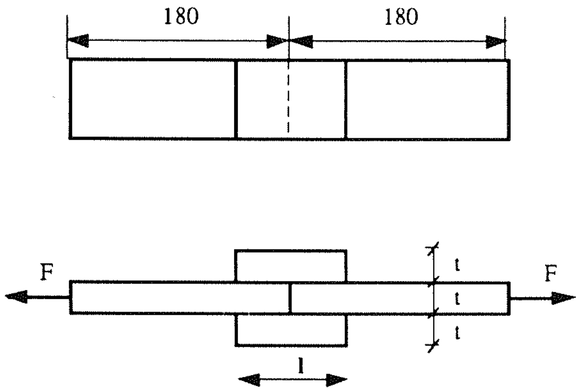

Fig.1 - Specimen geometry

Fatigue testing was carried out in a 25 ton servo-hydraulic MTS testing machine.

Specimens were instrumented to evaluate their straightness. All tests were carried out with R = 0.1 at a 10 Hz frequency, in air at ambient temperature. The adhesive A bonded specimens were tested at 3 maximum stress levels (84, 59 and 42 Nmm^{-2}). The specimens bonded with adhesive B were tested at a maximum stress level of 59 Nmm^{-2}

2.2 - Fatigue testing in humid condition

The specimens used in this series of tests were fabricated with 6061 T6 aluminium alloy with ultimate tensile strength and yield strength equal to 290 and 240 MPa respectively. The geometry of the specimen is ilustrated in Figure 1. Overlap was 72 mm for specimens bonded with adhesive A and 50 mm for specimens with adhesive B. Base material thickness was 6.35 mm and adhesive thickness was 0.3 mm.

Surface pretreatment was the same as reported for 5754 H32 specimens.

3 - RESULTS

3.1 - Specimens tested in air

The results of the fatigue tests are indicated in Table 1. The results obtained were subjected to a statistical analysis using the StatView 512 code. Fatigue data was plotted on log-log paper, with nominal stress (S) as the independent variable, and life (number of cycles N) as the dependent variable.

SN curves were drawn and are ilustrated in Figure 2 and 3 for joints bonded with adhesive A.

Figure 2 shows the SN curve obtained using the least squares method; Figure 3 ilustrates the 95% confidence intervals.

Table 1 - SN data for the 17 specimens tested.

Adhesive A		Adhesive B	
Nominal stress [MPa]	Number of cycles	Nominal stress [MPa]	Number of cycles
84	15200	59	156640
84	15570	59	241830
84	21070	59	492550
84	29940	46.4	4251740
59	150770		
59	217590		
59	263240		
59	311280		
42	1355500		
42	1612230		
42	1691210		
42	3024060		
42	3802780		

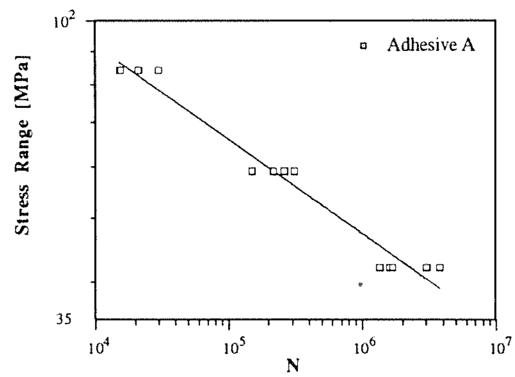

Fig.2 - SN curve for adhesive A

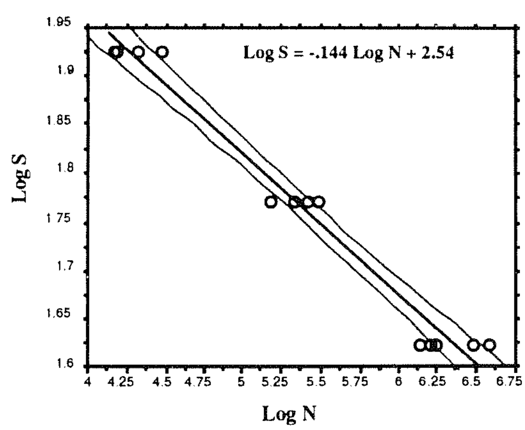

Fig.3 - 95% confidence intervals, data of Fig.2

The SN curve is expressed by

log S = 2.54-0.144 log N

The confidence intervals are defined by hyperboles but can be expressed by two straight lines, paralel to the SN curve and tangent to the hyperboles (this approximation is conservative for high or low stress levels), Figure 4:

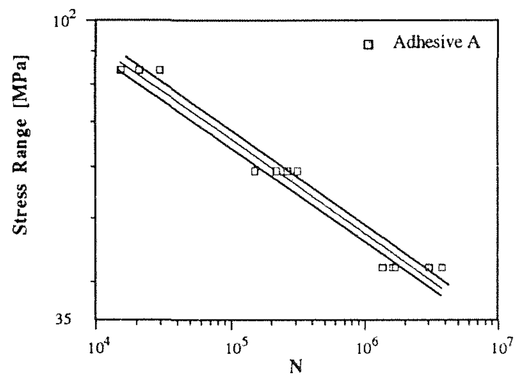

Fig.4 - SN data for adhesive A with approximate 95% confidence interval

In EUREKA EU269 project fatigue tests were carried out on cruciform welded joints, schematically presented in Figure 5, ref. [3]. Figure 6 presents all bonded joint data, obtained in air, plotted together with cruciform welded joints data. It can be seen that at the lower stress levels the bonded joints generally present longer fatigue lifes.

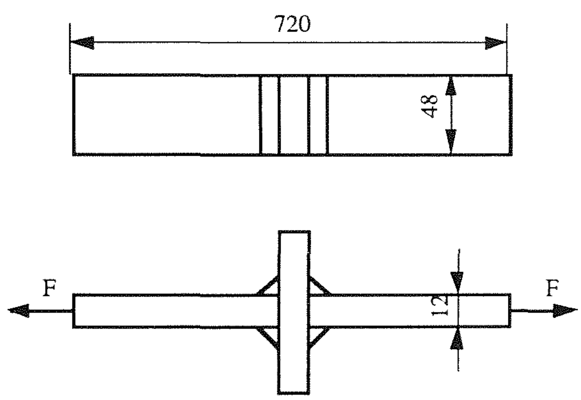

Fig.5 - Schematic drawing of the cruciform welded joint (6061-T651), ref.[3]

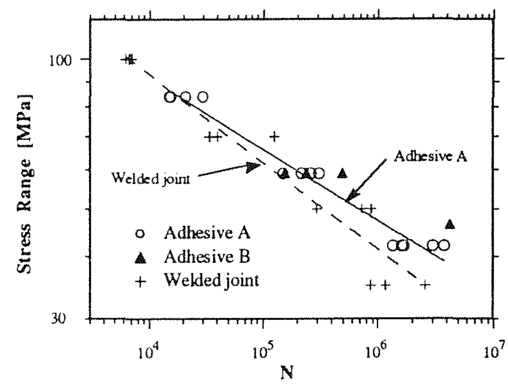

Fig.6 - Simultaneous plot of all adhesive data in air, and comparison wiht welded cruciform joints

Bonded joints with adhesive B seem to present higher fatigue strength. Further tests are however needed in order to confirm this conclusion.

Figure 7 shows a typical fracture surface for one of the adhesive joints tested. The fatigue crack propagated through the adhesive / base material interface (adhesive type of failure mechanism).

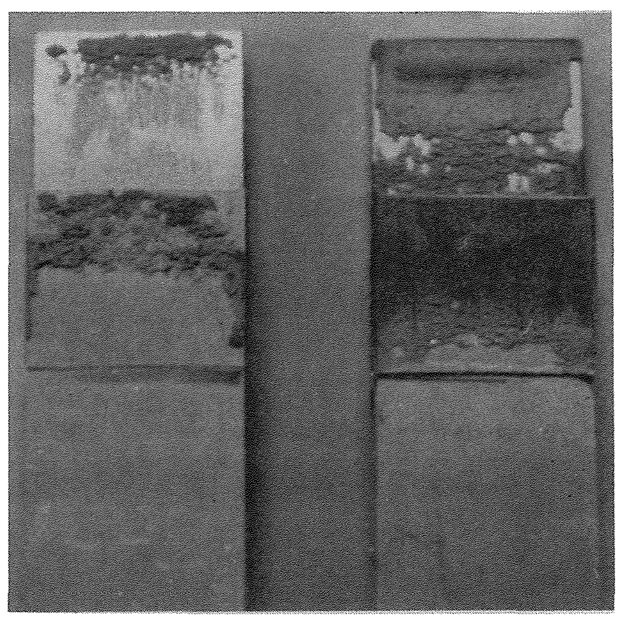

Fig.7 - Typical fracture surface

In the 17 specimens tested in this series, the maximum percentage of cohesive fracture found was 15%.

3.2 - Specimens tested in humid conditions

The results obtained in this series are presented in Table 2. Data already available for humid conditions is plotted simultaneously with results obtained in air in Figure 8.

Table 2 - SN data for the 12 specimens tested.

Al 6061/Adhesive A		Al 6061/Adhesive B	
Nominal stress [MPa]	Number of cycles	Nominal stress [MPa]	Number of cycles
204	6030	144	7490
102	28360	144	4920
102	15010	144	8090
102	22290	144	1690
102	16340	102	43890
		102	27100
		102	69740

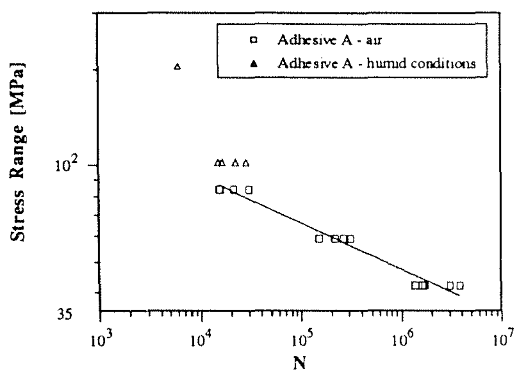

Fig.8 - Data for adhesive A, humid and air conditions

Further tests are still in progress and so it is not possible to present any conclusions at this stage.

4 - PRELIMINARY CONCLUSIONS

A SN curve and corresponding 95% confidence interval was evaluated for aluminium alloy 5754 H32 double butt joints bonded with adhesive A.

The bonded joint shows greater fatigue lifes than cruciform welded joints at lower stress levels; this seems to confirm results obtained by other researchers.

The limited amount of data obtained so far suggests that the adhesive B gives a slightly better fatigue strength than the adhesive A. Further tests are needed to confirm this conclusion.

At this stage it is not possible to present any conclusions in relation to the effect of testing environment.

5 - REFERENCES

[1] J R Fowler, 'The use of structural adhesives in the construction of rail vehicles', Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 1991, pp.131-135.

[2] M M Sadek, 'Industrial application of adhesive bonding', Elsevier Applied Science, 1987

[3] A S Ribeiro, F Oliveira, A A Fernandes, 'Fatigue testing of aluminium alloy welded joints, EUREKA project - EU269', progress report, Sept. 1992