FATIGUE BEHAVIOUR OF ADVANCED ALUMINIUM ALLOY LUGS OF 7475-T761 WITH AND WITHOUT INITIAL CRACKS

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ABSTRACT

7475 and 2024 Al-alloy lugs were tested under various test conditions. Spectrum and constant-amplitude tests showed that the total life of undamaged lugs of 7475-T761 aluminium alloy was not longer than that of conventional materials. This was probably because of the equally damaging effect of fretting in all materials compared. In the case of maneuver loading spectrum the crack propagation life of lugs with initial cracks was larger for the 7475-T761 lugs than for similar lugs made of 2024-T3.

KEYWORDS

Lugs, Advanced Al-alloy, Crack propagation, Maneuver spectrum.

INTRODUCTION

Developments in processing and alloy techniques have resulted in material and structure property improvements and increased potential applications for advanced aluminium alloys. The present investigation was undertaken to help ascertain whether the use of the more expensive advanced 7475-T761 material is feasible for lugs loaded with a maneuver spectrum, and what specific gains can be obtained with 7475-T761 compared to conventional materials. The investigation was a continuation of previous research performed on conventional materials.

COMPARISON OF LITERATURE DATA FOR 7475 AND OTHER AIRCRAFT MATERIALS

Material property improvement relative to conventional materials is obtained in 7475 by limitation of impurity elements such as iron and silicon. Some comparative results for fatigue properties have been published previously.

Wanhill (1978) compared the crack propagation lives (from 5 mm crack length to failure) of 7475-T761, 7075-T6, 2024-T3 and 2048-T851 sheet specimens under maneuver spectrum loading. The life of 7475 specimens was much longer than the life of other materials for the higher design stress level σ_{max} = 245MPa. For the lower design stress level σ_{max} = 195MPa the crack propagation life of 7475 and 2024 was nearly equal, but twice as long as for the other investigated materials.

Nowack and co-workers (1979) compared the fatigue lives of internally notched specimens (K_T = 3.6) made of 7475-T761, 7075-T6 and 2024-T3 sheets of 5 mm thickness. Fatigue tests were performed under TWIST and FALSTAFF standard loading histories with identical nominal maximum stress σ_{max} = 236.6MPa. For separation of the crack initiation and propagation phases a 0.5 mm crack length criterion was used. The 7475 material showed the highest number of flights to crack initiation under transport aircraft wing loading spectrum TWIST. Relative to this the crack initiation lives of 7075 and 2024 were only 75 percent and 50 percent as long, respectively. For the fighter loading spectrum FALSTAFF the differences between 7475 and 7075 were smaller than for TWIST. Regarding the total fatigue life the following ranking evolved for TWIST: 7475 - 100 percent, 2024 - 80 percent and 7075 - 63 percent. Under the FALSTAFF type of maneuver loading, the life to failure of 7075 was much smaller than for 2024 and the life of 7475 was only slightly longer than that of the 2024 specimen.

Crack propagation lives were given in an earlier investigation of the recent authors (1983) for σ_a = 31MPa for Technion lugs and for similar Fokker lugs made of 2024 and 7075 Al-alloys, Table 1. As can seen from Table 1, the obtained pulsating-tension tests for crack propagation lives of 2024-T351 and 7075-T7351 lugs fell within a nearly common scatter band, both for the Fokker and Technion lugs, in spite of the fact that the theoretical fracture mechanics estimates were two times larger for the 2024 lugs (98 kc for 2024 and 50 kc for 7075 for crack propagation to a 5 mm length). Also in the case of maneuver loading program the crack propagation lives were similar for both lug specimen series. However, the total fatigue life for this loading program was longer for the 2024-T351 lugs.

EXPERIMENTAL PROCEDURE USED FOR TESTS OF LUGS WITH AND WITHOUT INITIAL CRACKS

Lug specimens made of 7475-T761, 7075-T7351, 2024-T351 and 2024-T3 were used in the fatigue tests. The dimensions of the investigated lugs were as follows: lug width W = 60 mm, hole diameter D = 30 mm, and head length measured from the hole centre H = 34.5 mm. The stress concentration was about K_t = 2.7, according to a formula given by Heywood (1962).

The test loading program applied to the lugs was a fighter aircraft wing loading spectrum with randomized loading spectrum.

Table 2 presents the loading programs for different σ_{max} values used in tests. Program A was used for lugs without initial cracks, as in a previous investigation. Program B was used for lugs with initial cracks.

Crack starters were introduced at the critical cross-section in the form of a sharp mechanical through-cut, 1 mm deep, about 0.3 mm in width, with a notch root angle of about 21°. Two kinds of crack starters were used - through cracks on either side of the hole bore and crack starters on one side of the hole bore only.

The spectrum tests were performed with an MTS closed-loop servohydraulic

machine with test frequency about 10 Hz. The constant amplitude pulsating tension tests were carried out with a RUMUL-Schaffhausen electromagnetic resonance machine. The specimens tested were pin-lug joints without interference fit.

TEST RESULTS FOR 7475-T761 LUGS WITHOUT INITIAL CRACKS AND COMPARISON WITH SIMILAR RESULTS FOR 7076-T6 AND 2024-T3

Pulsating-tension test results obtained on 7475-T761 lug specimens without initial damage were compared with similar results for 7075-T6 and 2024-T3 lugs obtained in previous investigations (Buch, 1979; Schijve 1974). The total fatigue life obtained for the 7475 specimens was not better than the corresponding test results for lugs made of conventional materials 7075 and 2024. This may be explained by the effect of fretting which was probably equally damaging in all the materials compared. A similar conclusion may be drawn from spectrum test results. Two 7475 specimens tested with loading program A revealed a fatigue life of 8092 hrs and 8430 hrs. In similar tests performed on 7075-T6 specimens with program A the average fatigue life was 11444 hrs.

CONSTANT AMPLITUDE TEST RESULTS FOR 7475-T761 LUGS WITH INITIAL CRACKS

Test results for lugs with initial through-cracks from both sides of the hole bore or from only one side are presented in Table 3. As can be seen from Table 3 in both types of initial crack the number of cycles for crack propagation to failure is nearly identical. This is associated with the fact that in both cases the crack propagated mainly from one side of the hole.

For σ_a = 31.5MPa the crack propagation life was quite similar for the lugs made of 7475-T761 sheet material (t = 3.175 mm) and for those made of 2024-T3 (t = 4.8 mm) investigated before (Buch and Berkovits, 1983).

The average S-N line obtained for 7475 lugs with cracks from both sides was used for the damage calculations needed for prediction of the spectrum life with Miner's rule $\Sigma n/N_p = 1$ where N_p is the crack propagation life.

SPECTRUM LOADING TEST RESULTS FOR LUGS WITH AND WITHOUT INITIAL CRACKS

The spectrum test results obtained are presented in Table 4. The crack propagation life of 7475 specimens was nearly twice that of the lug specimens made of conventional materials. The life predicted with Miner's rule for lugs loaded with loading program B was 1052 flight hrs. The predicted life was a conservative estimate because the average test life of 7475 specimens was 2000 hrs for the lugs with two crack starters and 3097 hrs for the lugs with one crack starter. For the 2024-T351 lug specimen S2 with two crack starters the test life was 921 hrs and for the 2024-T3 specimens with one crack starter it was 1687 hrs on average (Table 4). The life predicted with Miner's rule was 1095 flight hrs. In the case of spectrum loading the cracks propagated from both sides of the hole for the lugs with two crack starters and from only one side for lugs with one starter. This explains the larger propagation life in the latter case.

DISCUSSION

The relatively accurate prediction of the maneuver spectrum life with Miner's rule seems to be associated with the absence of sequence effects, because the loading sequence was fully randomized and the higher loading peaks were fairly frequent (compared with gust loading programs). It should also be noticed that all loading levels of program B except the lowest were above the fatigue limit of the lugs with initial damage.

For the present damage calculations experimental constant amplitude crack propagation lives N_p were applied. However, because these lives may be obtained theoretically using the corresponding stress intensity factor, the spectrum life may also be predicted without knowledge of the specific S-N line of the initially damaged lugs.

The crack propagation life of 7475 lugs initially damaged on one side of the hole bore was for the loading program B about 3100 flight hrs, which shows better damage tolerance behaviour than for the 2024-T3 lugs (where N = 1687 hrs). It may be hoped that for lugs with expanded holes and for interference fit lugs (where fretting is much weaker) the gain obtained from the advanced Al-alloy 7475 will be larger than in the investigated case of clearance fit and hole bore without cold working. This must of course be substantiated experimentally.

CONCLUSIONS

The following conclusions can be drawn from this phase of the program:

1. Under maneuver loading spectrum the crack propagation life of lugs made of 7475-T761 was larger than the corresponding life of 2024-T3 lugs.

2. Under constant amplitude loading the crack propagation life and the total fatigue life were quite similar for both materials 7475 and 2024.

3. Miner's rule was applied successfully for prediction of spectrum life in the considered case of fully randomized maneuver loading spectrum.

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TABLE 1 Comparison of Crack Propagation Lives From 1 mm Initial Crack to Failure of the Technion Lugs and of Similar Fokker Lugs (Wanhill, 1980) D=30mm, W=60mm in both cases, Pulsating-tension, R=0.

Kind of lug and Artificial Crack	Material	Thickness mm	σ_a MPa	Propagation life Kc
Technion a_0=1 mechanical cut	2024-T3 2024-T351 7075-T7351	4.8 9.5 9.5	31.5 31.5 31.5	52-140 49-252 139-203
Fokker a_0=1 electric discharge	2024-T351 7075-T7351	5 5	30.4 30.4	16-38 28-47

TABLE 2 Fighter Wing-Loading Program used in Tests of Lugs.

Load Factor	n per 200 Flight hours	Program A Load Peaks P kg	Program A Nominal Stresses kg/mm² σ_{max}	Program A σ_a	Program B Load Peaks P kg	Program B Nominal Stresses kg/mm² σ_{max}	Program B σ_a
8	34	5760	20.14	9.44	4320	15.10	7.02
7	146	5040	17.62	8.18	3780	13.21	6.14
6	460	4320	15.10	6.92	3240	11.33	5.14
5	1080	3600	12.58	5.66	2700	9.44	4.25
4	2040	2880	10.06	4.40	2160	7.55	3.30
3	2740	2160	7.60	3.15	1620	5.66	2.36
0.5*	6500	360	1.26	-	270	0.95	-

*Valley level of all cycles.

TABLE 3 Constant Amplitude Test Results for 7475-T761 Al-Alloy Lugs (D=30mm) with Initial Cracks (a_o=1mm).

Spec. No.	Number of initial cracks	Lug Load Cycles P_{max} kg	P_{min} kg	P_a kg	Stress Ampl. σ_a kg/mm^2	Life N Kc
15A	2	1100	100	500	5.25	11.6
15B	2	1100	100	500	5.25	14.8
27A	2	1090	90	500	5.25	7.7
27B	2	1090	90	500	5.25	9.7
					geom. average	10.5
23A	2	720	92	314	3.3	53.0
23B	2	720	92	314	3.3	87.2
26A	2	720	92	314	3.3	31.1
26B	2	720	92	314	3.3	39.4
					geom. average	48.9
21A	1	640	40	300	3.15	50.4
22A	1	640	40	300	3.15	45.1
24A	1	640	40	300	3.15	69.0
					geom. average	48.7
28A	1	720	92	314	3.3	41.7
28A	1	420	92	314	3.3	41.7
29A	1	1090	90	500	5.25	9.8
29B	1	1090	90	500	5.25	9.8

TABLE 4 Spectrum Test Results for Al-Alloy Lugs (D=30mm) With and Without Initial Cracks (a_o=1mm).

Spec. No.	Material	Thickness mm	No. of Initial Cracks	Loading Program	Spectrum Fatigue Life No. of Cycles	Flight hrs.
S2	2024-T351	9.5	2	B	29947	921
S4	7075-T7351	9.5	2	B	37420	1157
					geom. av.	1032
S5	7475-T761	3.175	2	B	63050	1940
S10	7475-T761	3.175	2	B	51150	1547
S15	7475-T761	3.175	2	B	85320	2640
					geom. av.	2000
SW1	2024-T3	4.8	1	B	64645	1989
SW2	2024-T3	4.8	1	B	64676	1990
SW3	2024-T3	4.8	1	B	39446	1214
					geom. av.	1687
S6	7475-T761	3.175	1	B	129760	4000
S12	7475-T761	3.175	1	B	85532	2640
S13	7475-T761	3.175	1	B	91535	2816
					geom. av.	3097
S20	7475-T761	3.175	0	A	274000	8430
S21	7475-T761	3.175	0	A	263000	8092
					geom. av.	8260