Some aspects of test frequency influence on the fatigue behaviour of ARALL

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1. Introduction

ARALL laminates have been regarded as a highly fatigue insensitive aircraft material. Applications of this family of laminates for various aircraft structures are studied. A joint project of TU-Deift and Fokker has recently shown that ARALL 2HXX laminates can be successfully applied for the lower wing skin structures with a large weight saving and a high allowable stress level. The fuselage skin is another subject to be studied for ARALL laminate application.

One characteristic loading condition of an aircraft fuselage skin structure is the pressurization cycle for which the loading frequency is very low. It can vary between 30 minutes up to several hours a cycle. Because of the composition of ARALL material, it is necessary to investigate the influence of the loading frequency on the crack growth behaviour.

2. Materials and type of load wave shapes

According to Sun and Chim (ref.1) the time under static load (T in fig.1) has a large influence on the crack extension rate of the epoxy matrix system, even at room temperature (fig.1). After T exceeded a certain loading time, T0, the crack extension stabilized and no further crack extension was observed. The question is whether ARALL laminates will show the same tendency when fatigue cracks are present, since ARALL contains an epoxy matrix system. In view of this question two test series were carried out on sheet specimens (width=160.0mm). In the first series ARALL sheets with central saw-cut (a=30.0mm) were loaded at a constant stress. Subsequently the residual tensile strength of the specimen was determined with a constant loading speed (fig.2).

In the second series, fatigue tests with various test frequencies and wave shapes were carried out. Three different types of fatigue load were used (R=0, Smax=140 MPa, fig.3):

- type A: 1/6 Hz trapezoidal (2-2-1-1 sec.)
- type B: 1/6 Hz sinusoidal
- type C: 10 Hz sinusoidal

The materials tested were the following types of ARALL laminates: 2H32-as-cured, 2H32-prestrained, 7H32-as-cured and 7H32-prestrained. The codes imply: first digit, 2=2024-T3 and 7=7075-T6, H=high modulus aramid fibres, 32=2 alluminium alloy sheets of 0.3mm thickness. The nominal total thickness of the sheets is 0.82mm. Only one
specimen for each material has been tested in view of the very long testing time involved.
Both monolithic Al 2024-T3 and Al 7075-T6 sheets (thickness 1.0 mm) were also tested with a frequency of 15 Hz. It is assumed that the influence of the test frequency on the monolithic materials is negligible.
All static tests and the type A tests were carried out in an Amsler material testing machine. A special computer program was written for the type A tests. The type B, type C tests and the tests on the monolithic Al sheets were all conducted in a home built 6-tons material testing machine. The test stress levels are given in fig. 2 and fig. 3.

3. Test results

Static tests

The tests did not indicate any influence of the static preload time (T in Fig. 2) on the residual tensile strength of the ARALL laminates (Table 1). It was already known that the residual tensile strength of ARALL laminates is mainly dependent on the residual strength of the fiber-rich layer. Obviously, the static preloading at S=140 MPa has not affected the mechanical properties of the fibers. Some damage might have occurred in the matrix-rich layer of the laminate, but there is no apparent effect on the residual tensile strength of the laminate as a whole.

Fatigue crack growth tests

The results of the fatigue tests are given in figures 4 to 8. It turns out that the test frequency has a very large influence on the crack growth behaviour of the as cured ARALL specimens, whereas almost no effect on the crack growth behaviour of the prestrained ARALL specimens is observed. For the as cured material the crack growth rate at 1/6 Hz is significantly larger than at 10 Hz, while at 1/6 Hz the crack growth rate is larger for the trapezoidal wave shape as compared to the sinusoidal shape.
Figures 9 to 12 show the delamination areas around the cracks in the different specimens. No fiber failure has been found in the prestrained specimens, whereas all as cured specimens show a certain degree of fiber failure.
Comparing the crack growth behaviour of the monolithic aluminium sheet with the corresponding ARALL sheets, it is clear, that the as-cured ARALL laminates no longer have a large advantage over the
monolithic aluminium alloys, especially in the case of ARALL 2H32-as-cured loaded with very low frequencies (see figures 4 and 5).
4. Conclusions and recommendations

Residual strength and low frequency fatigue tests have been carried out on as-cured and on prestressed ARALL laminates (both 2H32 and 7H32). The following conclusions can be drawn from the test results.

-- The residual strength of ARALL laminates with a saw-cut of a=30 mm is not affected by a static preload at s= 140 MPa and preload times up to 20 hours. There is no obvious damage in the fiber layer of the material.

-- The test frequency has a very large influence on the fatigue crack growth behaviour of the as cured ARALL specimens. A test frequency reduction from 10 Hz to 1/6 Hz resulted in a 3 to 4 times higher crack growth rate in the as cured ARALL specimens. In these specimens fibre failure was observed.

-- Little or no frequency effect was found for the prestressed ARALL specimens. The fatigue crack growth occurred very slowly and showed typical ARALL behaviour, i.e. the crack growth rate decreased until crack arrest. Fibre failure was not observed.

-- The wave shape of the cyclic load (1/6 Hz) affected the crack growth rate of the as cured ARALL specimens. The trapezoidal wave shape increased the crack growth rate as compared to the sinusoidal wave shape.

Some recommendations concerning further research can be made:
First of all, the influence of the frequency on the crack growth behaviour of ARALL laminates in the as-cured condition needs more attention. The influence of much lower frequencies on ARALL laminates must be investigated. It is possible that this effect will stabilize when the frequency becomes very low. It is also important to know whether there are possibilities to reduce the frequency sensitivity of the as-cured ARALL laminates. It is also possible that biaxial load conditions and a bulge-out effect will improve the crack growth behaviour of ARALL laminates under low frequency test conditions. A first indication of this trend has recently obtained in a follow up program to be reported later.
5. References

1. Sun, C.T. and Chim, E.S.
Fig. 1 Loading time influence on crack extension in an epoxy system. Figure from ref. 1, scale units were not indicated.

Fig. 2 Loading sequence of the static loading tests.
Fig. 3 Loading spectra for fatigue tests
Fig. 4 ø-N curves for fatigue tests on ARALL 2H32-as-cured
Fig. 5 S-N curves for fatigue tests on ARALL 7H32-as-cured
Fig. 6 a-N curves for fatigue tests on ARALL 2H32-prestrained
Fig. 7 a-N curves for fatigue tests on ARALL 7H32-prestrained
Fig. 8 a-N curves for fatigue tests on aluminium alloy sheets

- 7075-T6

- 2024-T3

t = 1.00 mm
S = 70±70 MPa
a: sine 10 Hz (after 100,000 cycles)

b: sine 1/6 Hz (after 103,160 cycles)

c: trapezium 1/6 Hz (after 84,000 cycles)

Fig. 9 Prepreg of ARALL 2H32-prestrained (real size)
a: sine 10 Hz (after 80,000 cycles)

b: sine 1/6 Hz (after 67,150 cycles)

c: trapezium 1/6 Hz (after 110,000 cycles)

Fig. 10 Prepreg of ARALL 7H32-prestrained (real size)
a: sine 10 Hz (after 175,000 cycles)

b: sine 1/6 Hz (after 70,680 cycles)

c: trapezium 1/6 Hz (after 40,000 cycles)

Fig. 11: Prepreg of ARALL-2H32-as-cured (real size)
a: sine 10 Hz (after 80,000 cycles)

b: sine 1/6 Hz (after 54,000 cycles)

c: trapezium 1/6 Hz (after 28,900 cycles)

Fig. 12 Prepreg of AHALL-7H32-as-cured (real size)