MEMORANDUM M-560

Eddy-current inspection of visible cracks in a riveted lapjoint of ARALL-material

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1. Introduction

The application of ARALL material is primarily motivated by its excellent fatigue resistance. Fatigue crack growth is very slow, while high endurances are obtained for riveted and bolted joints of ARALL sheets (Ref. 1). In Reference 2 high endurances were obtained for so-called 1 1/2-dog bone joints under flight simulation loading (mini-TWIST). After more than 200,000 flights cracks could not be seen, but after dismantling of the joints small cracks near the edges of the bolt holes were visible on the mating surfaces of the joint. In order to explore whether such cracks occur relatively early in the fatigue life, similar specimens were tested by In 't Veld (Ref. 3), also under flight simulation loading, but now with the FALSTAFF load spectrum. During these tests an eddy-current apparatus of NLR (Mr. J.H. Heida) could be used, which indicated small growing cracks during the fatigue life. A correlation between the eddy-current indication and the crack size was not yet established.

Recently (12 September 1986) an opportunity was offered to test an ARALL riveted lap joint with a new eddy-current apparatus during a demonstration of the apparatus at NLR in the North East Polder. The lap joint had several small visible cracks, and possibly also invisible cracks. The results are reported in this document.

2. The ARALL riveted lap joint

The specimen is a single lap joint, see figure 1, with 3 rows of 8 countersunk rivets, diameter 3.2 mm. The ARALL sheet material consists of two 2024-T3 sheets (0.3 mm each) and an intermediate prepreg layer with unidirectional aramid fibres. The total ARALL sheet thickness is 0.8 mm. The ARALL material was 0.5% prestrained.

3. The fatigue load and the endurance

The lap joint specimen was cyclically loaded between \(S_{\text{max}} = 150\ \text{MPa}\) and \(S_{\text{min}} = 4\ \text{MPa}\) (\(\Delta S = 146\ \text{MPa}, R = 0\)). The test was stopped after \(2.3 \times 10^6\) cycles because a clamping failure occurred, see the edge crack at the bottom side in figure 1.
At that moment fatigue damage at the lap joint could also be observed, as described later.

Similar specimens of monolithic 2024-T3 material with the same rivet pattern and the same dimensions were tested by NLR (Ref. 4). A comparison of results obtained is shown below.

<table>
<thead>
<tr>
<th>Material</th>
<th>Joint</th>
<th>Endurance at $\Delta S = 146$ MPa, $R = 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2024-T3 thickness 0.8 mm</td>
<td>riveted, riveted and bonded</td>
<td>30 000, 350 000 and 700 000 (*)</td>
</tr>
<tr>
<td>ARALL</td>
<td>riveted</td>
<td>$&gt; 2300 000$</td>
</tr>
</tbody>
</table>

(*) Results for two cold setting adhesives, failure at end of overlap and not through rivet holes.

4. Fatigue damage of the ARALL specimen

4.1. Visible damage before dismantling the specimen

A schematic cross section of the specimen is presented in figure 2 in order to define the numbering of rivet rows and sheets.

The edges of the countersunk rivets of the end row in sheet A (row No. 1) are obviously damaged, see figure 3. Small fragments of the edges came out, which should be attributed to fatigue. The fatigue load of the joint was very high for such small countersunk rivets. During the fatigue test it could be observed that significant bending occurred in the lap joint, which implied a cyclic shear rotation of the rivets in the holes. The thin ARALL sheets and the countersunk rivets have a low resistance against this heavy deformation. As a consequence there is a cyclic bending on the countersunk edges of the rivets, which then fail by fatigue. During the test black powder (fretting corrosion) was released and small pieces of the edges broke away. In the middle row of rivets minute fragmentation of the countersunk rivet head edges could also be observed, see figure 3.
Cracks in the ARALL outer Al-sheets (A1 and B1) could be observed in the end rows of rivets (No. 1 in sheet A, No. 3 in sheet B), as illustrated by figure 3 and 4. The cracks were more abundant in sheet A where in general more than one crack occurred at each side of the rivet hole, see figure 3. As a result a small piece was removed from the outer Al-sheet A1, see rivet 8 in figure 3.

No cracks could be observed at rows 2 and 3 in sheet A and at rows 1 and 2 in sheet B.

4.2. Damage revealed after partially dismantling of the specimen

The specimen was cut between rows 2 and 3 (fig. 2). The rivets of rows 1 and 2 were then removed in order to separate sheets A and B. The inside sheets A2 and B2 (mating surfaces of the lap joint) could thus be inspected for 'inside' cracks. Such cracks were found, especially at row No. 1, but also at the middle row (No. 2), see figures 5 and 6. Row No. 3 was not (yet) dismantled.

In row No. 1 the cracks in sheet A2 were more numerous and larger than in sheet B2, which should be expected because of the end row effect in sheet A. Parallel cracks can be observed in sheet A2, which were observed in ARALL before. In monolithic Al-alloy sheet material parallel cracks are rather exceptional because one crack will soon dominate other ones. However, in prestrained ARALL the aramid fibres take care of the continuity of the material, even if there are cracks in the Al-sheets. Parallel growing cracks can then occur.

Various cracks occurred just outside the rivet holes. This was especially true for the middle row for both sheets A2 and B2. For both rows 1 and 2 there is a clear tendency for cracks to occur in sheets A2 and B2 at opposite sides of the hole. This is schematically indicated in figure 7. Both local bending and fretting corrosion might contribute to this phenomenon. Also after dismantling the inside sheets (A2 and B2) suggested a fairly severe shear rotation load on this rivets. Actually the rivets should be considered to be either too small or to give insufficient clamping. Comparative fatigue tests on ARALL riveted lap joints with rivets of 3.2 and 4.8 mm (not yet published) indicated life improvement factors in the order of 10 or more (actually failure could not be obtained with rivets of 4.8 mm within a reasonable testing time, and the tests were
stopped). The application of Briles rivets also gave significant life improvements. Briles rivets are supposed to give a better filling up of the countersunk hole (Ref. 5).

5. The eddy-current inspection

The eddy-current inspection was carried out with a NDT-19 portable Eddyscope. The inspection was concentrated on the middle row of rivets (No. 2 in figure 2), because no cracks could be externally observed before dismantling the specimen. The inspection was made by moving a small pencil probe around the rivets by guiding the probe inside a circular hole of a plastic mould plate. The oscilloscope pictures obtained are shown in figure 8. Apparently it indicates cracks at all eight holes in row No. 2. After dismantling small inside cracks turned out to be present at all holes. The correlation between the crack size and the eddy-current indication was not so obvious. However, it should be noted that the inspection method adopted was an improvised procedure. With special eddy-current probes and/or better scanning procedures a correlation between crack size and eddy-current indication might well be obtained.

Two eddy-current indications were obtained at hole No. 7 (row No. 2) which indeed corresponds to two cracks at this hole.

6. Conclusions

(1) A (prestrained) ARALL lap joint with countersunk rivets fatigue tested at \( R = 0 \) showed a very high fatigue resistance as compared to a similar monolithic 2024-T3 riveted lap joint. Observations on the fatigue damage in the ARALL joint indicates that further improvements can be obtained by either a larger rivet diameter or a type of rivet for better clamping. Such improvements will give more restraint to shear rotation of the single shear rivets.

(2) Small invisible cracks at the inside Al-sheets of ARALL were easily indicated by eddy-current inspection.

Acknowledgment: The eddy-current examination was carried out by J.H. Heida (National Aerospace Laboratory, NLR) and R.C. van Dijk (AIMS NDT b.v.). The eddy-current apparatus was made available by AIMS NDT b.v. for this purpose.
References


Figure 1: The ARALL riveted lap joint. Specimen width 160 mm.

Figure 2: Cross section of overlap. Numbering of rivet rows and sheets.
Row No. 1 = end row in sheet A.
Row No. 3 = end row in sheet B.
Figure 3: Countersunk rivet heads of rows 1 and 2 in sheet A.
Magnification: 2.2x
Figure 4: The rivet die heads of row No. 3 in sheet B. Magnification 2x.
Figure 5: Internal cracks in sheet A revealed after dismantling.
Figure 6: Internal cracks in sheet B revealed after dismantling.
Figure 7: Crack initiation sites of the inside cracks just outside the rivet holes.
Figure 8: Eddy-current indications of the internal cracks in the middle row of rivets.