Memorandum M-507

THE INELASTIC RATIO OF ARALL

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INTRODUCTION

The inelastic ratio (IR) is a laminate property which characterizes the elastic recovery of the laminate after being deflected up to a certain substantial strain in the outer metal layers. The inelastic ratio is a parameter for the flexural elasticity of the material. The parameter is only defined for laminates consisting of materials with plastic deformation capability.

TEST PROCEDURE

The test procedure is defined in the ASTM standard D790-71 and can be described as follows:

A sheet specimen with standardized width (b = 12.7 mm) is subjected to a 3-point bending test. The span of the flexural test fixture is a function of the thickness of the specimen whereby:

\[ L = 16d \quad \text{if } d > 1.72 \text{ mm} \]
\[ L = 25.4 \text{ mm} \quad \text{if } d < 1.72 \text{ mm} \]

\( L \): span
\( d \): thickness specimen.

The span defines the length of the specimen whereby:

\[ l > L + 12.7 \text{ mm} \]

\( l \): length specimen.

The deflection is executed with a defined crosshead deflection rate \( (D = 0.212 \text{ mm/s}) \) up to a specified deflection \( D_0 \) (Fig. 3) whereby:

\[ D_0 = \frac{rL^2}{600d} \]

\( r \): substantial strain in outer metal layer
\( = 5\% \)

If \( D = D_0 \), the flexural loading has to be removed with a crosshead deflection rate of 8.46 mm/s.

The specimen is immediately removed and allowed to relax freely. After a limited period (one or two days) the residual deflection \( D_R \) reaches an equilibrium value \( D_R \). The inelastic ratio is now calculated as:

\[ IR = \frac{D_R}{D_0} \times 100 \]
configuration 1:

\[ E_1 = \frac{t_{Al}}{t_{tot}} \cdot E_{Al} + \frac{t_{pr}}{t_{tot}} \cdot E_{pr} \]

whereby

- \( t_{Al} = 1.23 \text{ mm} \)
- \( t_{pr} = 0.23 \text{ mm} \)
- \( E_{Al} = 72000 \text{ N/mm}^2 \)
- \( E_{pr} = 65000 \text{ N/mm}^2 \)

\[ E_1 = 70691 \text{ N/mm}^2 \]

configuration 2:

in this case \( E_{pr} \approx 0 \)

\[ E_2 = 58536 \text{ N/mm}^2 \]

configuration 3:

- \( t_{Al} = 1.5 \text{ mm} \)
- \( t_{pr} = 0.46 \text{ mm} \)
- \( t_{tot} = 1.96 \text{ mm} \)

\[ E_3 = 70360 \text{ N/mm}^2 \]

configuration 4:

\[ E_4 = 55100 \text{ N/mm}^2 \]

With increasing deflection, the stresses in the aluminium sheets are identical for all the specimen configurations (the total stresses are not!) so the deflection at which plastic deformation occurs will be identical for all configurations. The specimens with fibres in width direction have a plastic behaviour controlled by the aluminium sheets and can be regarded as ideal plastic (fig. 2). The elastic contribution of the fibres of specimens with fibres in length direction on the force-deflection curve in the plastic range is considerable. As can be seen in fig. 2, this results in a lower \( D_R \) values and therefore a lower IR value.
EXPERIMENTAL DETAILS

4 different ARALL configurations have been tested:

1) ARALL build up of 2 aluminium layers (7075-T4; individual sheet thickness: 0.5 mm) and 1 prepreg layer (thickness: 0.23 mm) with unidirectional fibres oriented in the length direction of the specimen.

   length specimen: 50 mm
   width specimen: 12.7 mm
   thickness specimen: 1.23 mm

2) ARALL with the same configuration as in 1) but fibres oriented in the width direction of the specimen.

3) ARALL build up of 3 aluminium layers (7075-T6; individual sheet thickness: 0.5 mm) and 2 prepreg layers (individual thickness: 0.23 mm) with fibre orientation of both prepreg layers in the length direction of the specimen.

   length specimen: 50 mm
   width specimen: 12.7 mm
   thickness specimen: 1.96 mm

4) ARALL with same configuration as in 3) but fibre orientation of both prepreg layers in the width direction of the specimen.

To avoid possible scatter problems, all ARALL configurations enclose 4 to 6 specimens.

RESULTS

The results are shown in table 1, the average data and accessory standard deviation of every configuration are shown in fig. 1.

The inelastic ratio of ARALL is about 65 \% whereby the mutual differences between the configurations are negligibly small. The small difference in IR-values between specimens with fibres in length and width direction is the result of the different elastic-plastic behaviour of the specimens (fig. 2). The elastic part of the force-displacement curve is controlled by the Young's modulus of the specimens which is a function of the composition of the material:
configuration 1:

\[ E_1 = \frac{t_{Al}}{t_{tot}} \cdot E_{Al} + \frac{t_{pr}}{t_{tot}} \cdot E_{pr} \]

whereby
\[ t_{Al} = 1.23 \text{ mm} \]
\[ t_{pr} = 0.23 \text{ mm} \]
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configuration 2:

in this case \( E_{pr} \approx 0 \)

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Table 1: Inelastic ratio of 4 different ARALL configurations

configuration 1 (1.1-1.6)
2 (2.1-2.6)
3 (3.1-3.6)
4 (4.1-4.4)
Fig 3: Definition of the critical deflection $D_0$ and $D_r$. 