

# Master thesis plan

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## 1 Objectives

This thesis is focusing on the characterization and the modeling of the failure in fatigue of the RTM6 epoxy resin. This resin is a material highly used in aerospace thanks to its flexibility and its high glass transition temperature for a light weight. Experimental tests will be performed to understand how cracks initiate and propagate in the material and to quantify the material degradation through the decrease of its mechanical properties during cyclic loading (i.e. stiffness and residual strength). The main objective is to find a failure criterion for this resin in fatigue, based on the extension of an existing failure criterion developed for quasi-static loadings.

## 2 Experimental tests and methods

### 2.1 S-N curves

The curve gives the number of cycles to failure under a particular loading condition.

### 2.2 Mechanical properties degradation

- Stiffness drop
- Residual strength and comparison with static strength
- Link to defect's size

### 2.3 Fracture analysis

- Fractography and comparison with fracture surface under static loading
- Micro defect propagation into cracks.
- Void growth
- Size of critical defects
- CT fracture mechanics samples (true crack propagation)

## 2.4 Fracture criterion

Extension of the static criterion to fatigue, based on critical defects growth and final size.

## 3 Experimental test campaigns

- Tests under quasi-static loadings.

- CT Specimens

Manufacturing of the CT specimens, testing under cycling loading and analyzing of the fracture surface with a scanning electron microscope (SEM).

- Tension-tension

The manufacturing of the samples (cylindrical dog-bone) is important and the polishing has to be done very carefully.

Different tests will be performed to analyze the effect of several parameters like the mean stress and the frequency and an analysis of the fracture surface with the SEM will be done.

- Shearing and compression-compression

The main issue for those tests is the frequency. An innovative setup for the experiment is needed to be able to reach a frequency that is high enough.

## 4 Analysis of test results and discussion

- CT Tests

The tests are carried out for the calculation of the fracture toughness and to analyse the crack propagation. The results will allow to draw a curve of  $\frac{da}{dN}$  over  $\Delta K$ , and to find the Paris law for this material. A comparison of the fracture surface in static and in fatigue will also be done.

- Tension - tension tests.

The tests allow to draw the curve of the stress  $S$  over the number of cycles  $N$ . They also allow to analyse the effect of several parameters like the mean stress or the frequency. A comparison of the fracture surface under quasi-static loadings and under cycling loadings will be done with the fracture surface of the CT specimens. The fractographic studies will enable a quantitative analysis of the critical defects and their growth or propagation prior to final failure.

- Shearing and compression - compression tests.

The main issues of the compression tests are the sensitivity to friction and the barreling effect.

- Fracture criterion

A fracture criterion is to be defined based on all the results of the experiments.

## 5 Numerical analysis

A finite element analysis is to be performed with the software Abaqus. This analysis will model the mechanical tests that have been performed and compare them with the actual results.

## 6 Technical resources and contact persons

Supervisors: Jérémy Chevalier, Thomas Pardoën.

Machining: Marc Sinneave, Alban Maton.

SEM: Laurence Ryelandt.

Polishing: Jonathan Lorfèvre.

Mechanical tests: Marc Sinnaeve, Quentin Mestrez.

Static tests machine: Zwick Z250.

Cyclic tests machine: Instron 50kN.

## 7 Bibliography and references

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Sanita Zike, Bent F. Sorensen, Lars P. Mikkelsen
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Martin Maier, Volker Altstidt, David Vinckier, Klaus Thoma
- Characterizing the toughness of an epoxy resin after wet aging using compact tension specimens with non-uniform moisture content  
Gustavo Quino, Jalal El Yagoubi, Gilles Lubineau
- Mechanical fatigue of epoxy resin  
M. Nagasawa, H. Kinuhata, H. Koizuka, K. Miyamoto, T. Tanaka, H. Kishimoto, T. Koike
- Micro-mechanics based pressure dependent failure model for highly cross-linked epoxy resins  
J. Chevalier, X.P. Morelle, C. Bailly, P.P. Camanho, T. Pardoën, F. Lani
- Repeatable pre-cracking preparation for fracture testing of polymeric materials  
Nithiananthan Kuppusamy, Rachel A. Tomlinson
- Mechanical characterization and physics- based modeling of highly-crosslinked epoxy resin  
X.P. Morelle
- Fractography analysis and fatigue strength of carbon fiber/RTM6 laminates  
Maria Odila Hilário Cioffi, Herman Jacobus Cornelis Voorwald, José André Marin Camargo, Mirabel Cerqueira Rezende, Edmundo C. Ortiz, Luigi Ambrosio
- Cyclic Deformation Behavior of an Epoxy Polymer.  
Xinghe Shen, Zihui Xia, and Fernand Ellyin
- Ratcheting behavior of an epoxy polymer and its effect on fatigue life.  
Gang Tao, Zihui Xia

## 8 Expected schedule

### Planificateur de projet

