"DYNAMIC BEHAVIOR OF UNIDIRECTIONAL AND CROSS-PLY FLAX/EPOXY LAMINATES MADE OF A HYBRID UD-MAT REINFORCEMENT"

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Introduction

Overview

Context

Investigation of the impact load and fatigue behavior on laminated composite materials

Comparison between UD and cross-ply flax/epoxy laminates

Flax fibers

One of the best among the natural fibers in terms of mechanical properties

The UD-mat reinforcement used in this study is relatively new

No similar studies were ever conducted on such materials

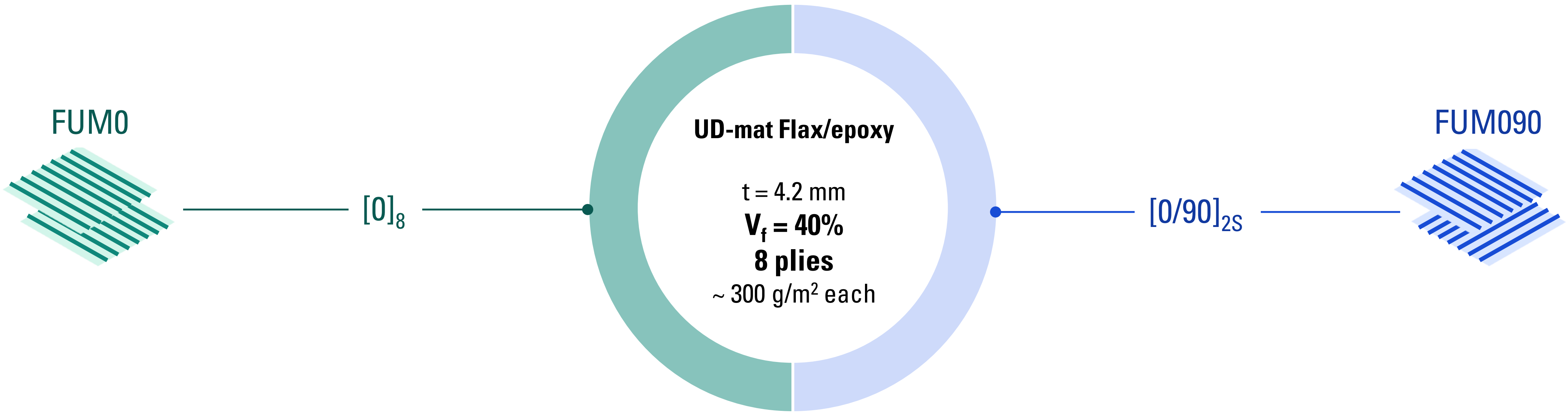
Objective

Impact and fatigue behaviors

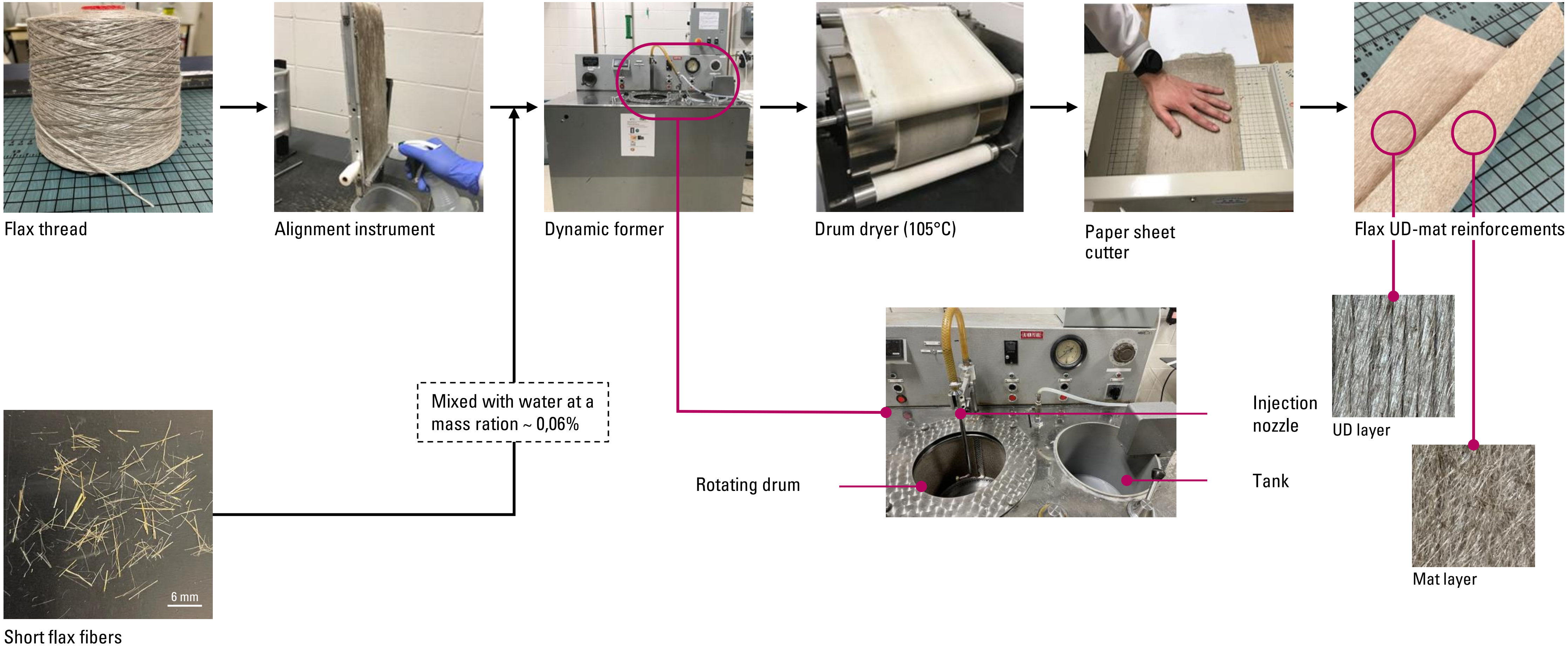
Necessity of materials characterization under dynamic loads

Limited research on the fatigue of NFC which is insufficient for engineering design

Materials


FUM0
$[0]_8$
UD-mat Flax/epoxy
t = 4.2 mm
V_f = 40%
8 plies
~ 300 g/m^2 each
$[0/90]_{2S}$
FUM090

Reinforcements fabrication

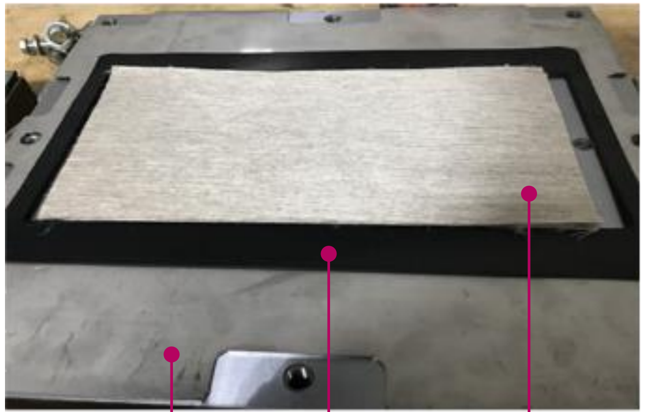


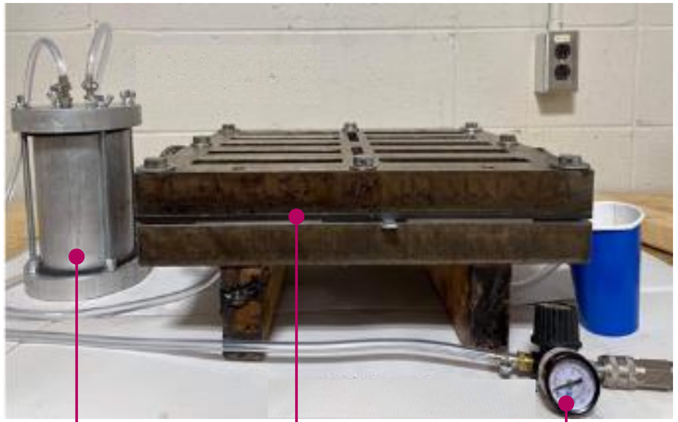
Molding (RTM process)

Reinforcements placement according to the desired configuration

Epoxy resin injection

Molded plate





UD flax/epoxy

Mechanical tests

Parameters

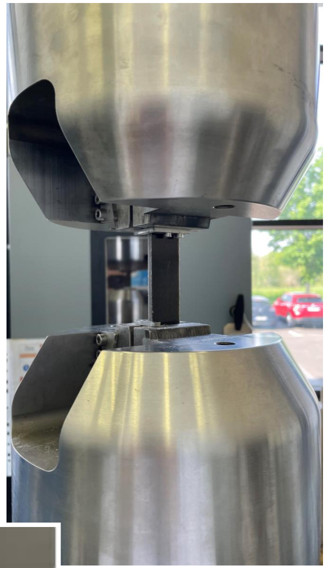
Tensile tests (Servo-hydraulic test machine Instron 8801, force capacity up to 100 kN)
– **ASTM D3039/D3039M**
Head displacement rate = 2 mm/min

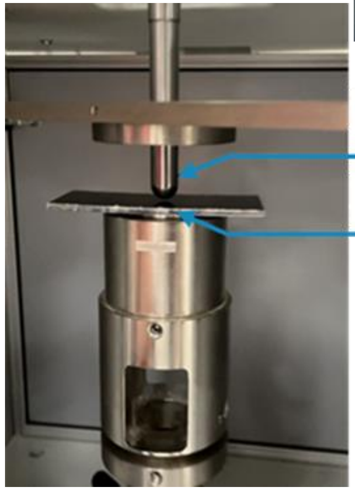
Fatigue tests – ASTM D3479/D3479M
Load ratio, R = 0,1 (=$\sigma_{min}/\sigma_{max}$)
Frequency, f = 5 Hz
Load levels: 40%, 60% and 80% of the ultimate tensile strength (UTS)

Impact tests (Instron CEAST 9350 Drop tower) – ASTM D7136/D7136M
Impact energies = 3, 5, 8 and 11 J

Test	Dimensions (mm x mm x mm)
Tensile and fatigue	150 x 25 x 4,2
Impact	150 x 90 x 4,2

For each laminate :
Five tests were conducted for tensile tests
At least 3 tests were conducted for each fatigue level and for each impact energy





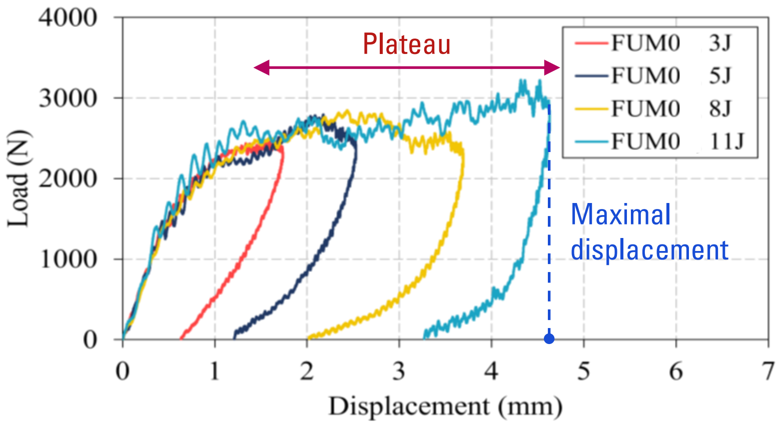
Hemispherical impactor
ø = 20 mm

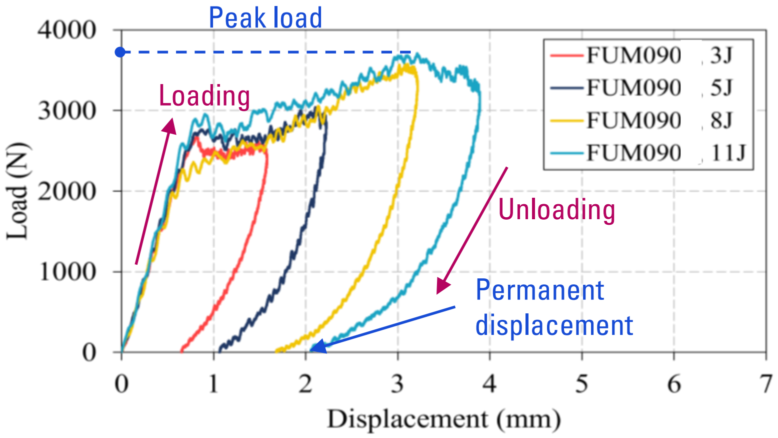
Specimen for calibration

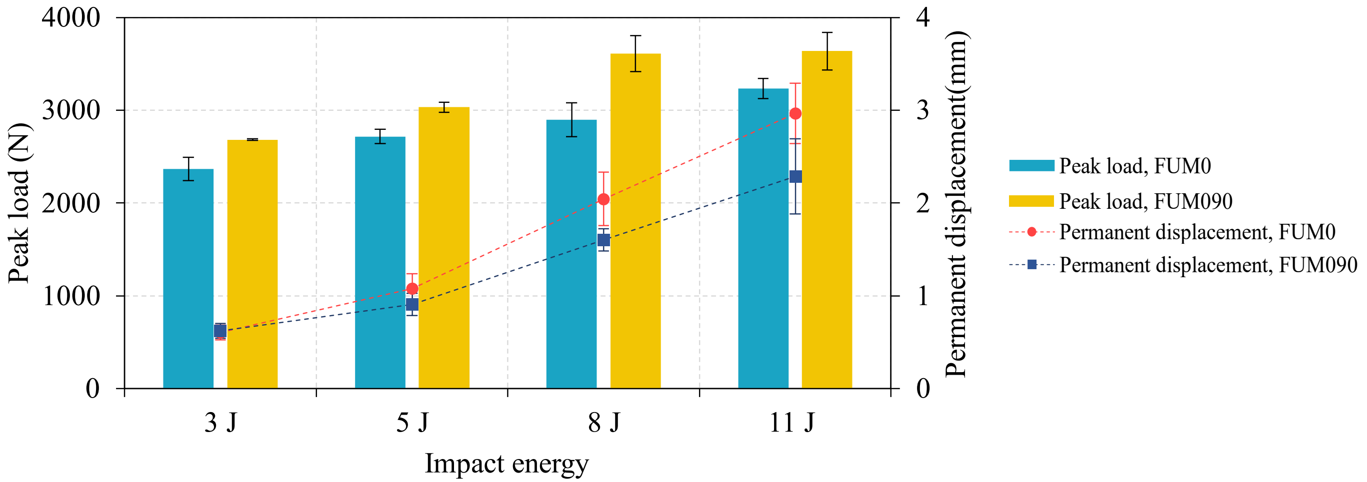
All tests are performed at room temperature

Results

Impact tests – Load-displacement curves



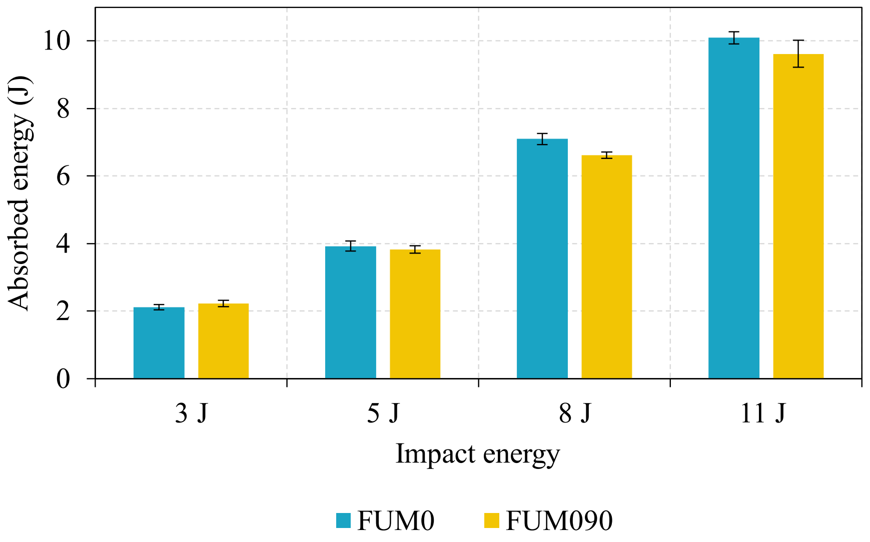


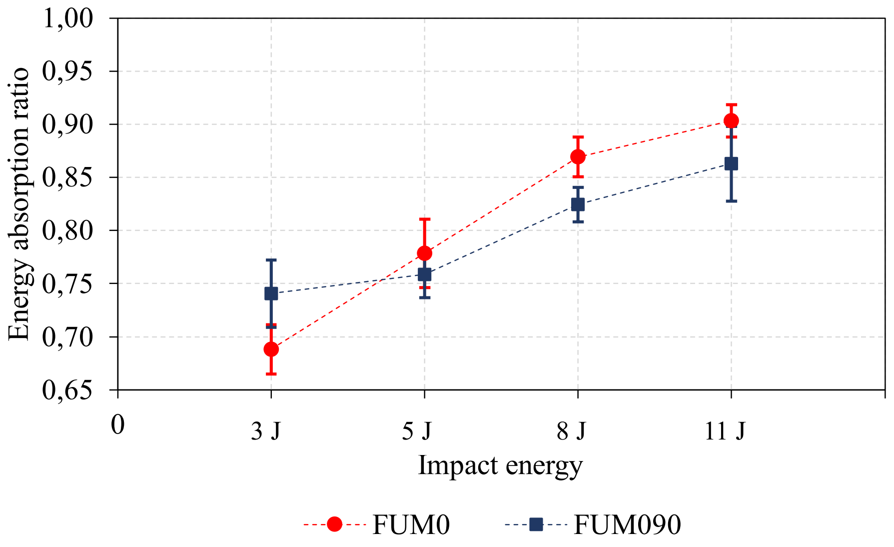


- Peak loads :
  - higher ones for FUM090
  - progressive increase for FUM0
  - stabilization starting at 8J for FUM090
- Permanent displacements :
  - progressive increase for both laminates
  - higher ones for the FUM0 starting at 5J

Results

Impact tests – Energy absorption





- High absorbed energy which increases progressively with the impact energy
- Energy absorption ratio (E_{abs}/E_i) :
  - increases progressively
  - although both of the laminates exhibit comparable ratios, starting at 5 J a higher absorption ratio is recorded for the FUM0

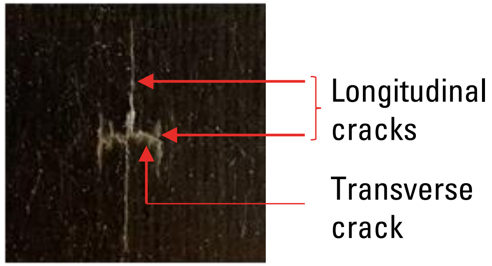
This shift can be explained by an earlier occurrence of fiber breakage in the UD laminates, potentially absorbing more energy than matrix cracks and delamination

Results

Impact tests – Damage inspections at 5 J et 8 J for FUM0

Visual inspections

FUM0, $E_i = 5$ J



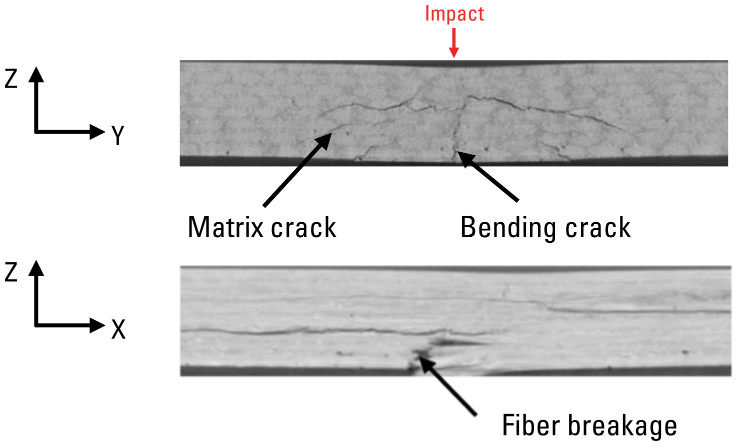
Rear face

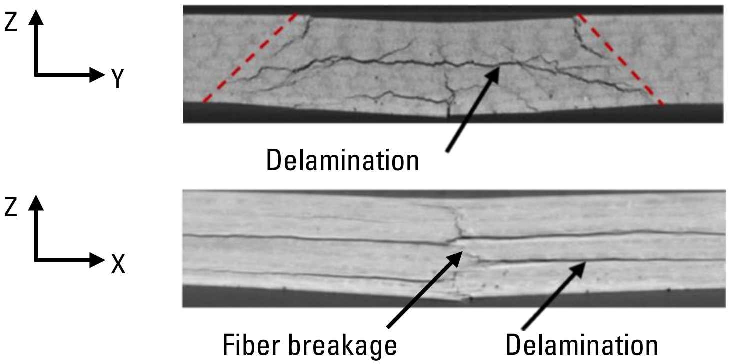
FUM0, $E_i = 8$ J

Rear face

20 mm

Microtomography





5 mm

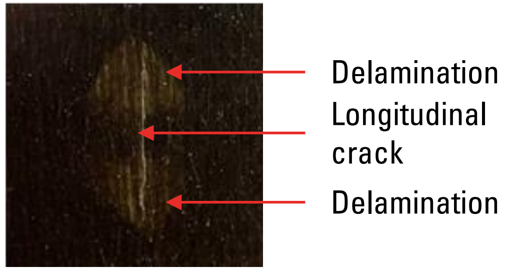
- Damages – FUM0 at 5 J :
  - Longitudinal and transverse cracks
  - Matrix and bending cracks
  - Fiber breakage starting at 5J
- Damages - FUM0 at 8 J :
  - Elliptical shape of the damaged zone
  - Delamination and propagation of damages in a conical shape
  - Fiber breakage intensification

Results

Impact tests – Damage inspections at 5 J et 8 J for FUM090

Visual inspections

FUM090, $E_i = 5J$

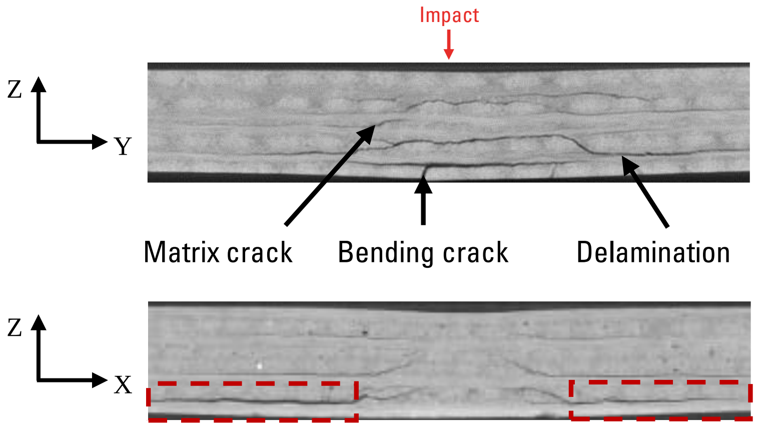


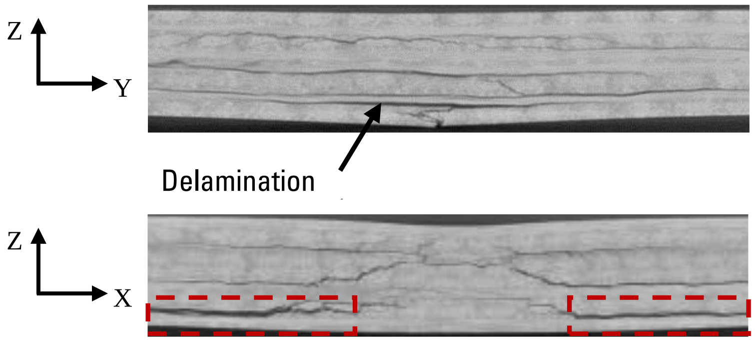
Rear face

FUM090, $E_i = 8$ J

Rear face

Microtomography





20 mm

Visible delamination on the rear face

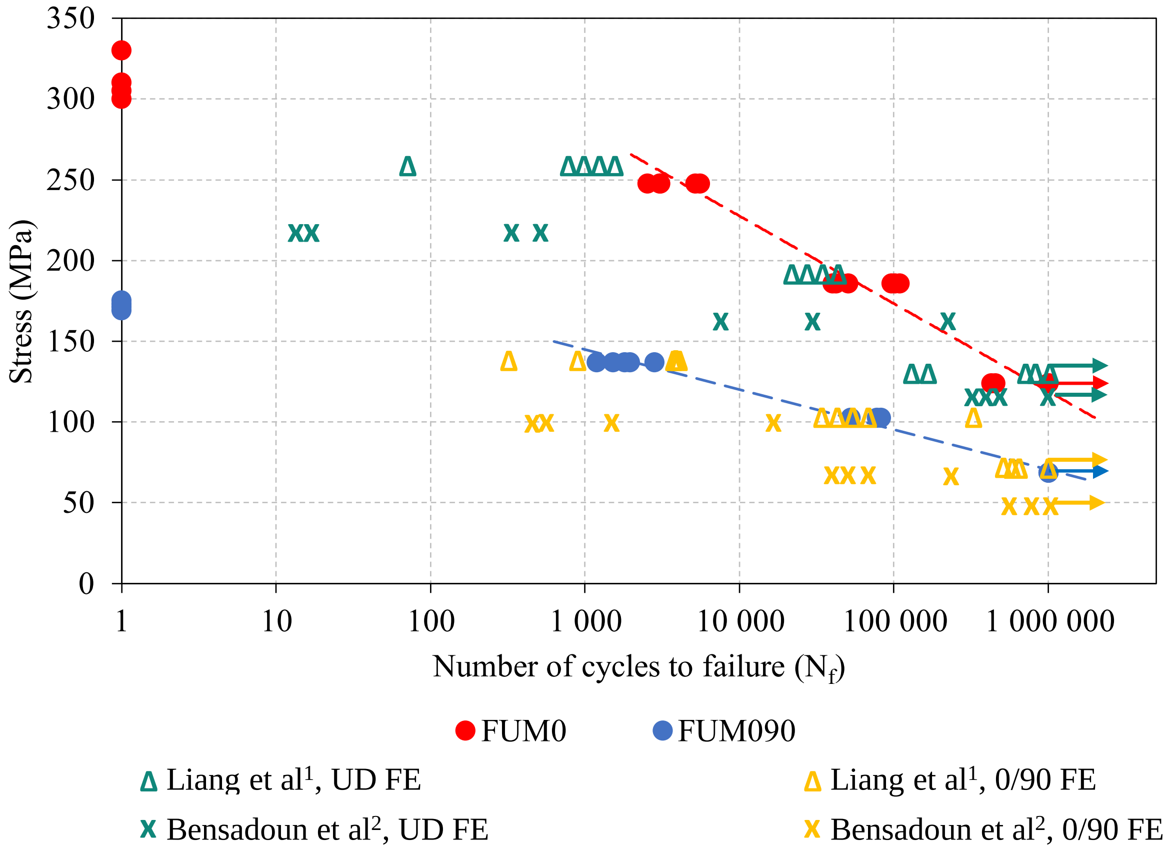
5 mm

- Damages - FUM090 at 5 J :
  - Butterfly shape
  - Longitudinal crack
  - Delamination (dominant damage mode), matrix and bending cracks
  - No detected fiber breakage

- Damages - FUM090 at 8 J :
  - Widening of the damaged area,
  - Delamination and propagation of damages in a conical shape.

Results

Fatigue tests – S-N curves



- Higher fatigue life for the FUM0
- Wöhler's model and damage kinetics:

$$log(N_f) = A + B\,\sigma_{max} \quad \rightarrow \quad \sigma_{max} = \alpha\ log(N_f) + \beta$$

Material	α (MPa/log(cycles))	β (MPa)
FUM0	-54,30	444,74
FUM090	-24,85	219,55

→ The cross-ply laminates show a better fatigue stability and a slower damage kinetics

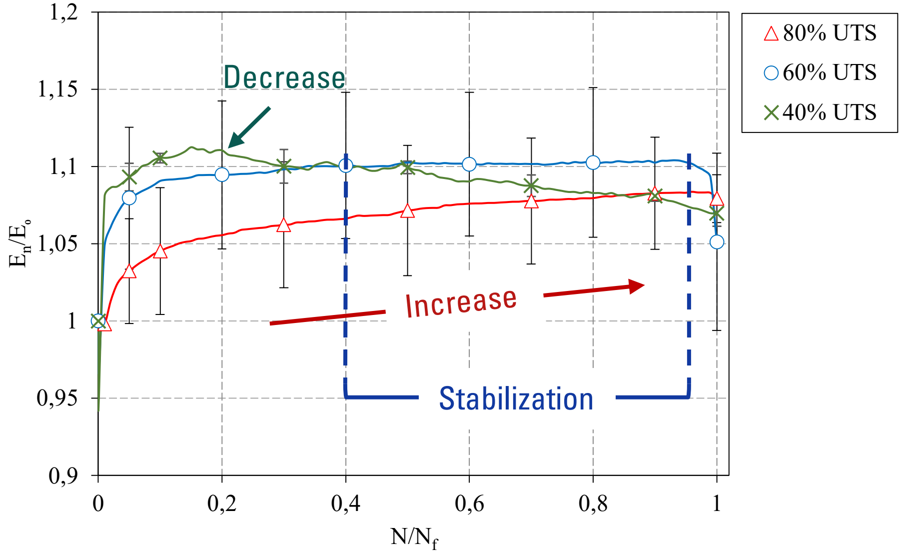
- The presence of the flax mat in the reinforcement seems to ameliorate the fatigue behavior due to the fatigue life obtained, when comparing to some reported results in the literature

[1]Liang S, Gning P-B, Guillaumat L. Properties evolution of flax/epoxy composites under fatigue loading. Int J Fatigue 2014;63:36–45
[2]Bensadoun F, Vallons KAM, Lessard LB, Verpoest I, Van Vuure AW. Fatigue behaviour assessment of flax-epoxy composites. Compos Part A-Appl S 2016;82:253–66

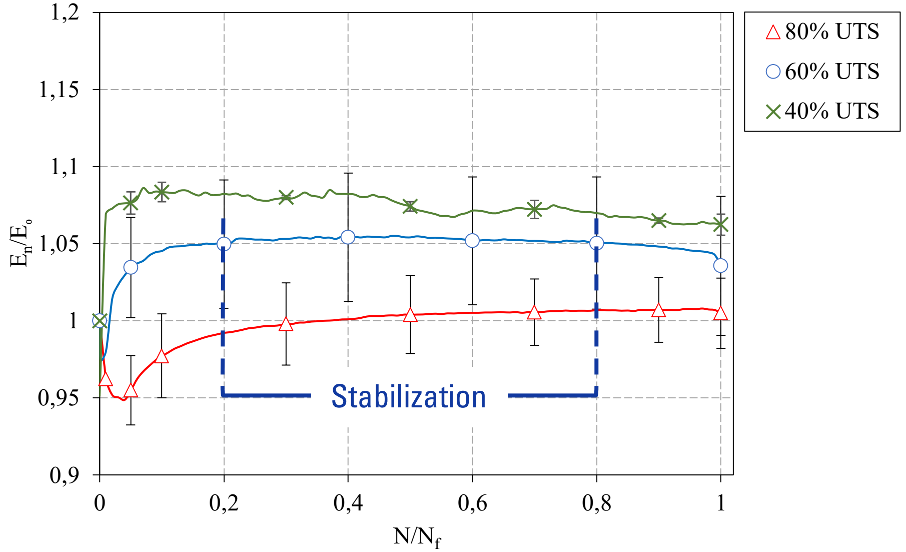
Results

Fatigue tests – Secant modulus evolution

FUM0



FUM090



Despite the large standard-deviation a **stiffening effect** is observed for **all fatigue levels** and **for both laminates**

Cases with quasi-stabilization (60% UTS), others with a continuous increase (80% UTS) or notable decrease (40% UTS)

FUM0 :

- Stiffening at 40% UTS followed by a progressive decrease of the stiffness starting at $0.2N_f$
- **More pronounced stiffening effect** (on average : 8 – 11 %)

FUM090 :

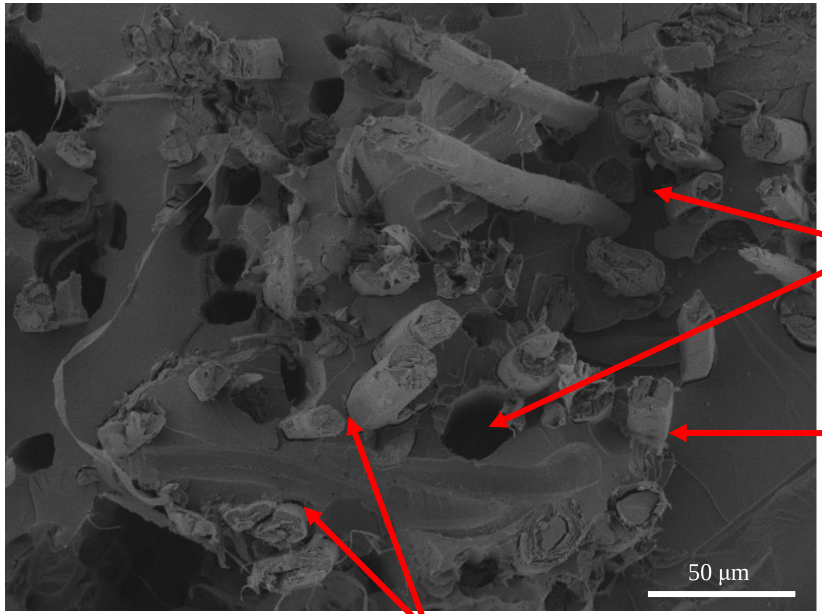
- Stiffening effect : 1 – 9 %
- **Higher stiffening for lower fatigue levels**

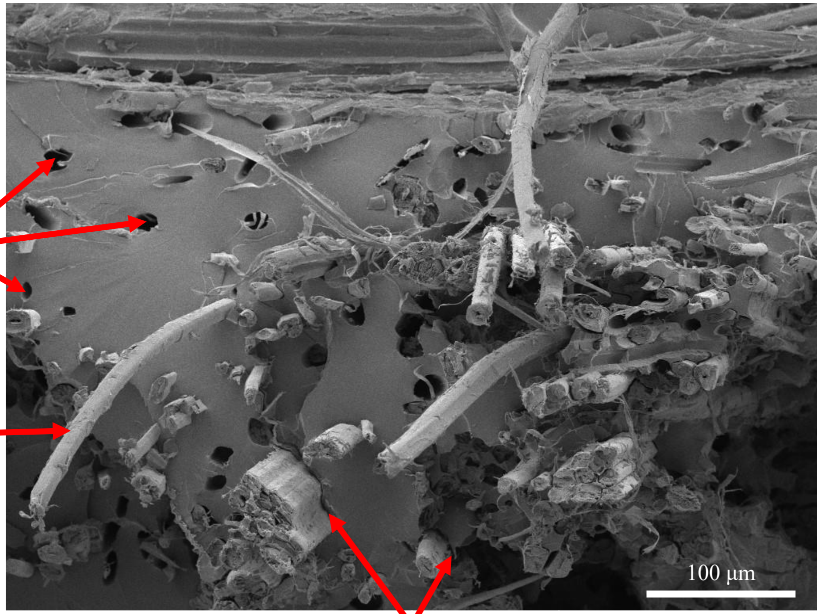
Results

Fatigue tests – SEM images

FUM0 tested under fatigue loading, σ_{max} = 80% σ_R

FUM090 tested under fatigue loading, σ_{max} = 80% σ_R





Fiber print

Fiber pull-out

Fiber-matrix debonding

Brittle failure of the matrix

Fiber-matrix debonding

Conclusion and future outlook

Impact

- FUM090 have a better impact response than the FUM0
- High energy absorption for both laminates
- Fiber breakage and matrix cracks for FUM0 and mainly delamination for FUM090

Fatigue

- Slower damage kinetics for FUM090
- Stiffening effect, on average :
  - 8 – 11 % for FUM0
  - 1 – 9 % for FUM090

Fatigue after impact of the same materials of this study

Thank you for your attention !

Any question ?

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