Lignocellulosic fiber reinforced composites: influence of compounding conditions on defibrization and mechanical properties

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► To cite this version:

Johnny Beaugrand, Françoise Berzin. Lignocellulosic fiber reinforced composites: influence of compounding conditions on defibrization and mechanical properties. *Journal of Applied Polymer Science*, 2013, 128 (2), pp.1227-1238. 10.1002/app.38468 . hal-01267981

HAL Id: hal-01267981

<https://hal.science/hal-01267981>

Submitted on 29 May 2020

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Impact of thermo-hydro environment and specific mechanical energy on defibring using flow modelling and extrusion

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(Fractionation of lignocellulosic resources and Environment)

Lignocelluloses defibring

We know: final composite properties = f (initial fibre quality & comportment under processing conditions)

Wood / long fibres

Extrusion

Transformation

+ Polymer matrix

Compound/Composite material

Lignocelluloses defibring

Individualisation

Extrusion

And **Fragmentation**

Compound/Composite material

Δ Distribution profile

We know: Aspect ratio ' L/W ' and size influence composite end uses properties

Is it possible to control the defibring in order to enhance the mechanical properties of composites?

Control of the defibring : hypothesis about fibre' ruptures locations?

Inter fibres (individualisation)

Intra fibres (fragmentation)

Structure

decohesion

dammage

Theorical L/W

Theorical material reinforcement

origins?

First strategy : playing on fiber polymer mobility

Macroscopic impact

Rupture location

From Salmén and Olsson 1998

Second strategy : playing on extrusion process

Taken from glass fibre

Transposable to natural fibres?

SME Specific Mechanical Energy (kWh/t)
intensity of the thermomechanical treatment

$$SME = \frac{1}{Q} \frac{N}{N_{max}} r \frac{C}{C_{max}} W$$

$$L_n(t) = [L_0 - L_\infty] \exp(-k' SME) + L_\infty$$

Where:

Q is the mass feed rate,

N is the screw speed,

N_{max} the maximum screw speed (680 rpm),

r the motor efficiency (0.93),

C the torque,

C_{max} the maximum torque,

W the nominal power (9.2 kW)

Materials and methods

❑ Materials

ϵ -caprolactone $\rightarrow T_{melting} : 60^{\circ}\text{C} - M_w : 80.000 \text{ g/mol}$

Hemp bast fibre 20 % (w/v) $\rightarrow$ 2 cm length on average

❑ Extrusion

Laboratory scale twin-screw extruder (Clextral BC 21)

❑ Trials

Compounding caprolactone / fibres in different conditions

Analyze of fiber L/W in compounds

Analyze of mechanical properties Young modulus and $\text{Yield}_{\max}$ (tensile tests)

❑ Simulation/modeling of the fibre' thermomechanical history

Twin-screw extrusion modeling software

- ❑ LUDOVIC[®] : global model based on mass and thermal balance equations allowing to calculate the principal flow parameters

Vergnes et al., Polym. Eng. Sci., 1998 <http://www.siconsultants.com>

- Pressure
- Shear rate
- Temperature
- Residence time
- Filling ratio...

Extrusions set up

Screw profile 1 'hard'

Study of formulation (at constant screw speed 250 rpm and feed rate 0.85 kg/h)

- Influence of fibre water content: 9 – 14 – 23 (%)
- Influence of temperature: 100 – 140 (°C)

Screw profile 2 'soft'

Study of extrusion conditions (at constant humidity 50% and temperature 100°C)

- Influence of screw speed: 100 - 200 - 300 - 400 (rpm)
- Influence of feed rate: 0.85 – 1.5 (kg/h)

Characterization – Extruded hemp fibres

□ Fibres morphology (L/W)

Optical Image Analysis

Fibres elements L/W

Results: effects of extrusion conditions

- Computation of the total SME and SME received by fibers

- Good fitting of experimental and simulated SME for total energy
- Slight underestimation of SME calculated by LUDOVIC[©]

Results: conditions of twin-screw extrusion

- Effects of screw speed and feed rate (profile 2)

- SME ↗ if screw speed ↗
- SME ↘ if feed rate ↗

Results: characterization of fibres

- Effects of formulation (profile 1, 250 rpm, 0.85 kg/h)

- Fibres water content ↗ → L/W ↗
- Extrusion temperature ↗ → L/W ↘

Results: characterization of fibres

- Effects of extrusion conditions (profile 2)

□ Screw speed ↗ → $L/W \approx$
□ Feed rate ↗ → $L/W \nearrow$

Results: influence of extrusion conditions

○ Effects of SME

□ $L = L_{\infty} + (L_0 - L_{\infty}) \exp(-K \cdot \text{SME})$
 $L_0 = 2000 \text{ mm}$, $L_{\infty} = 400 \text{ mm}$ and $K = 0.003 (\text{kWh/t})^{-1}$

□ L and $L/W \searrow$ with SME

□ L and $L/W \searrow$ with profile 1

Results: mechanical properties

- Effects of formulation (profile 1, 250 rpm, 0.85 kg/h)

- Water content $\nearrow$ $\rightarrow$ Stress and Young modulus $\nearrow$ at 100°C
- Different behavior at 140°C

Results: mechanical properties

- Effects of fiber aspect ratio (profile 1, 250 rpm, 0.85 kg/h)

- Aspect ratio ↗ → Stress and Young modulus ↗
- Influence of temperature

Results: mechanical properties

- Effects of extrusion conditions (profile 2)

- Low or no effect of screw speed
- Feed rate ↗ → Stress and Young modulus ↗

Results: mechanical properties

- Effects of fibre aspect ratio (profile 2)

- Mechanical properties (stress at break and Young modulus) are affected by L/W

Results: properties – morphology correlation

- Effects of fibre aspect ratio (profiles 1 and 2)

- No identical properties between screw profiles 1 & 2
- Problem: at identical L/W ratio → ≠ material properties

Is it possible to control the defibring in order to enhance the mechanical properties of composites?

- Yes, partial control of the defibring can be done and useful for mechanical properties enhancement
 - Fiber defibring depends on extrusion conditions (rotation speed and feed rate) through SME
 - To favour ↗ L/W: twin-screw extrusion at high feed rate (low SME) as for glass fiber (limit breakages)
- No simple relation between L/W and mechanical properties: other influences (size and fibre adhesion...)

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Financial support:

MATOREN program

Division for Science and Process
Engineering of Agricultural Products