Damage of the Cell Wall During Extrusion and Injection Molding of Wood/HDPE Composites

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Wood Plastic Composites, WPC

Why…?

OBJECTIVE

Establish **quantitative correlations** between **mechanical properties**, **microstructure** and **phase properties** on WPCs produced with different wood species.
The hypothesis…

**Increase in strength due to:**
- Better stress transfer
- Better Interface contact (no interface voids)
- Lumen filled by the Matrix (mechanical Interlocking)

**Decrease in strength due to:**
- Poor mechanical interlocking
- Matrix voids
- Interface voids
- Damage on The cell wall

Grand fir, Outerwood

Lodgepole pine, Outerwood
**Outline**

**Wood species properties variability**
- Inside the log
- Among species
  - Grand fir
  - Douglas fir
  - Lodgepole pine

**Wood anatomical features**
- Cross Section
- Longitudinal Section

**Physical interaction wood/HDPE**
- HDPE - Solid wood
- Injection Molding WPC

**Wood Characterization**
- Macroscale
  - Outerwood
  - Corewood

**IM-Composites**
- Microscale
Extrusion - Composites

IM - Composites

Nanooscale

Microscale

Macroscale

Nanoindentations on wood cells

Before – after processing

Cellular collapse

Void content

Particle alignment

Microstructure:

Low performance Composites

LP-outerwood

Interconnectivity in wood particles

High performance Composites

GF-outerwood

WPC properties = \( f \) (cellular morphology of wood)

Wood particle – HDPE

Wood species & location effects

Mechanical interlocking

Wood characterization

Mechanical properties
METHODS

IM composites
HDPE – wood physical interaction

Extrusion: Leistritz 18 mm twin screw Extruder

Injection: Sumitomo SE 50D.

AOI = 770 \times 880 \ \mu m^2
Image treatment: Pruning filter, threshold = 53

AOI for SEM
RESULTS

IM - WPC’s microstructure

![Bar chart showing wood species and void content.](image-url)
IM – WPCs
Mechanical Properties

**Bending**

- MOE - Flexure (MPa)
  - DFin
  - GFout
  - GFin
  - DFout
  - LPPin
  - LPPout

**Tensile**

- MOE - Tensile (MPa)
  - GFout
  - DFin
  - GFin
  - LPPin
  - LPPout
  - DFout
IM - WPCs,
Damage of the cell wall

\[ E_1 = D^f E_1^f V^f + E^m (1 - V^f) \]
Nanoindentation test

\[ E_r = \left[ \frac{1 - \nu_s^2}{E_s} + \frac{1 - \nu_i^2}{E_i} \right]^{-1} \]

\[ E_r = \frac{\sqrt{\pi}}{2} \frac{S}{\sqrt{A}} \]
RESULTS

Wood species nanoproperties

![Graph showing Young's Modulus (GPa) for different wood species and layers.](image)
IM - WPCs and Wood properties

### Thermoplastic phase

- **Bulk HDPE**
- **TCL HDPE**

### Latewood proportion

- **DFin**
- **LPPout**
- **GFin**
- **DFout**
- **GFout**
- **LPPin**

### Modulus reduction after processing

- **Lodgepole pine**
- **Grand fir**

**Wood Specie**

- **E-LP**
- **E-LP-A**
- **L-LP**
- **L-LP-A**
- **E-GF**
- **E-GF-A**
- **L-GF**
- **L-GF-A**

After processing
IM - WPCs properties prediction

\[
E_1 = D^f E_1^f V^f + E^m (1 - V^f)
\]

\[
E_D = \frac{E_b - E_a}{E_b}
\]

\[
D^f = D_E + D_L = E_w (1 - E_{DE}) + L_w (1 - E_{DL})
\]
METHODS

Extrusion of WPCs

Adapted model

\[ E_1 = D^f E_1^f V^f + E_1^m (1 - V^f) \]

\[ D^f = D_\theta^f D_D^f \]
Microstructure characterization

Extrudate, cross section

Wood particle orientation

AOI, 770x880 μm²

LP65-0

GF65-2
Modulus reduction after IM

Cell wall properties After Extrusion

Modulus of Elasticity (GPa)

Young's Modulus (GPa)

Wood Specie

After processing
Extrusion vs. IM
Wood particles orientation

Wood Particle orientation (degrees)
Extrusion trials
Properties prediction

\[ E_1 = D^f E_1^f V^f + E_1^m (1 - V^f) \]

New ideas…

\[ E_1 = D^f E_1^f V^f + D^m E_1^m V^m + E_1^{TCL} V^{TCL} \]
CONCLUSIONS

- Anatomical features ~ The phase morphology and mechanical properties of WPC.

- A poor interpenetration of HDPE ~ Free buckling of cell walls during extrusion.

- Wood particle alignment and wood particle degradation may affect final properties of WPCs made in different processes.
Thanks... 

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Background: Wood structure

Pine: Wood flour 60 mesh

De Magistris, 2005

Gacitu-Wolcott, 2005
Mechanisms of Adhesion in WPC

Bond as a system...

Mechanical Interlocking

Chemical Adhesion

Source: Harper D., Wolcott M., 2004

Gacitua W., Wolcott M., 2005

Source: Harper D., Wolcott M., 2004