



**IMT Mines Alès**  
École Mines-Télécom



## *Séminaire IMT « Vers des produits bois à hautes performances environnementales et durables »*

### **Towards sustainable wood fillers from agroforestry for Wood-Plastic Composites (WPC)**

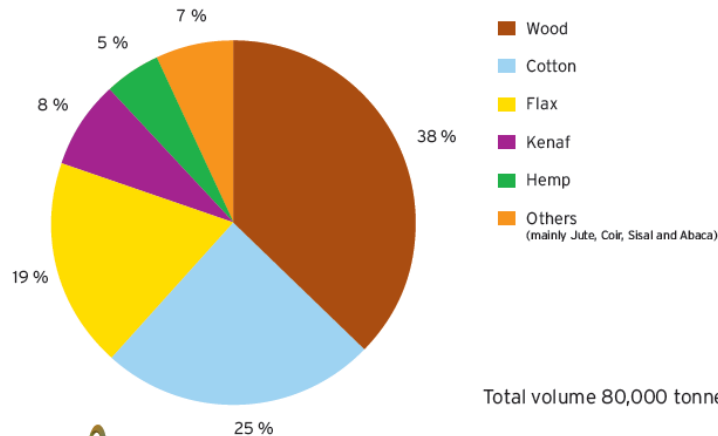
Nicolas Le Moigne, Fabien Liagre, Stéphane Corn, Estelle Doineau, Benjamin Gallard, Jean-Christophe Quantin, Joana Beigbeder, Alexis Duborper, Arnaud Day, Stéphane Dumarçay, Philippe Gérardin



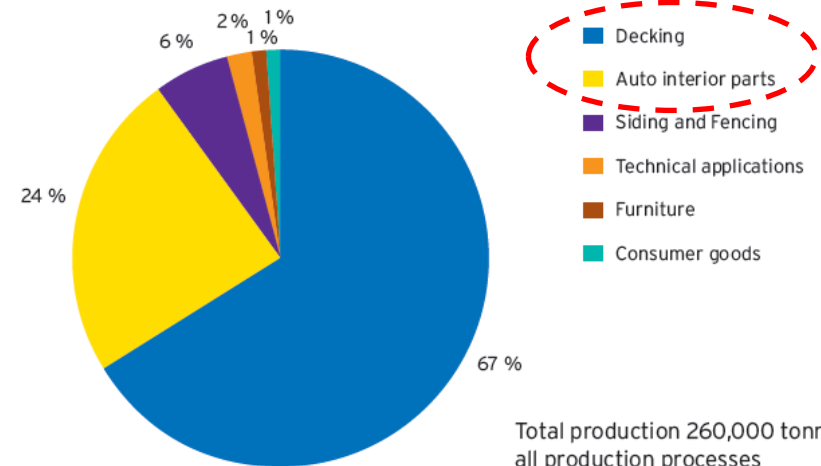
# INTRODUCTION

## WPC : Market and application of biocomposites by sector and fibre type

Use of Wood and Natural Fibres for Composites in the European Automotive Industry 2012



Application Fields of WPC in Europe 2012



**Worldwide production in 2015 :  
3.8 million tons**

# INTRODUCTION

Why **studying wood fillers** for WPCs and expected **scientific outcomes** ?

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- ▶ Major **technological bottleneck** for **WPCs (Wood Plastic Composites)** = variability in mechanical performance related to **traceability and quality** of the biomass, fibre **extraction** and composite **manufacturing** processes.
- ▶ To better understand the influence of **wood fillers characteristics** (biochemical composition, thermal behaviour, microstructure, etc.) on the **final mechanical properties of composites**.

## Objectives :

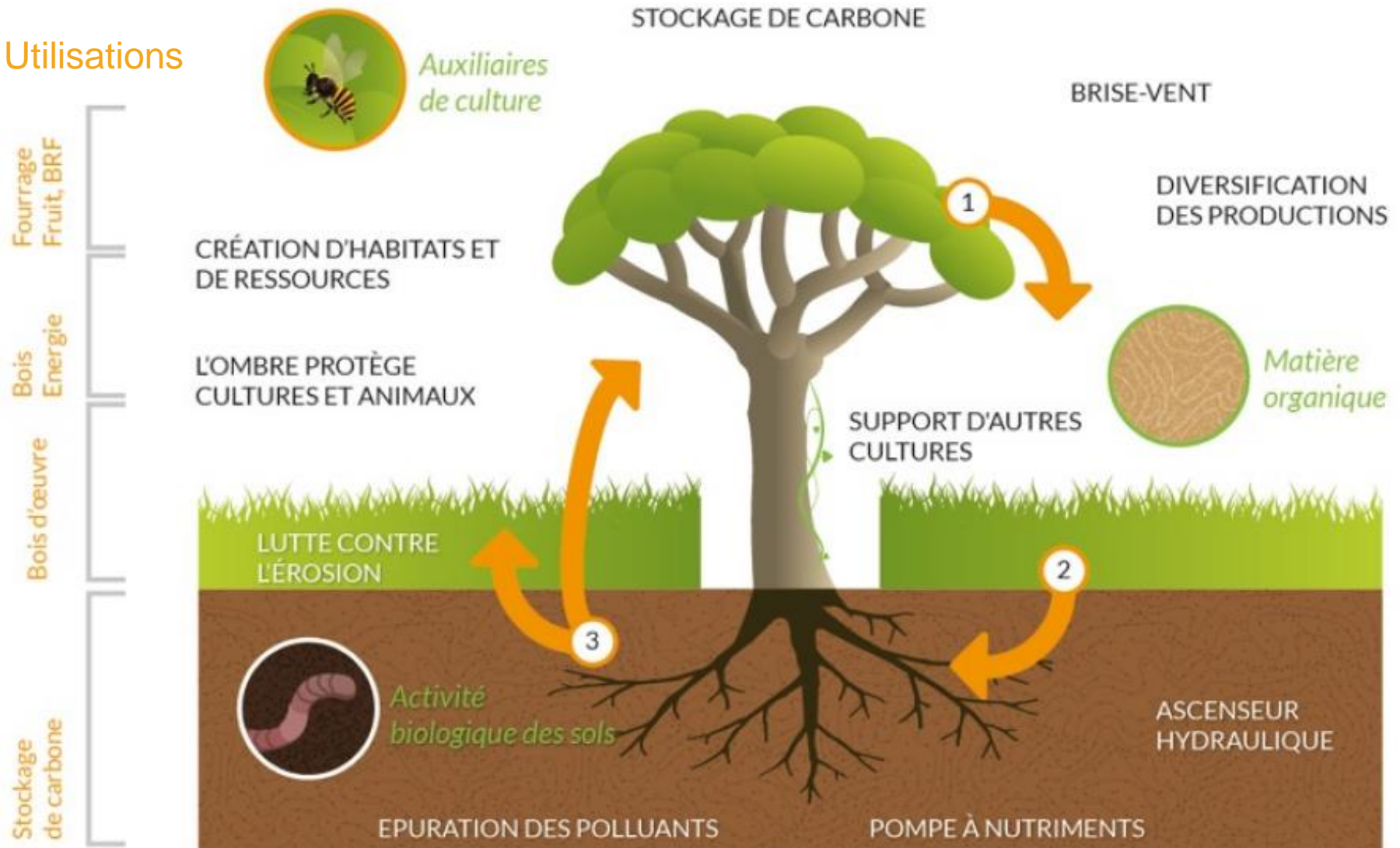
- **Influence of filler granulometry ?**
  - **Influence of wood species?**
- ...on the **microstructure** and **mechanical performance** of bio-based composites

# INTRODUCTION

## Agroforestry as a source of multi-purpose biomass

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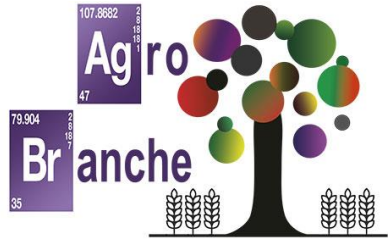
### Utilisations



*Schéma théorique des fonctions et services de l'arbre dans les SAF – Crédit : H2E-SIMA-PECAT.*

# INTRODUCTION

The Agrobranche project (2018-2022)



Valorization of tree branches from agroforestry for the bio-based materials and chemistry sectors



The promise of new, **high-value-added outlets** for farmers?



Inter-parcel



Intra-parcel



## ➤ Project methodology



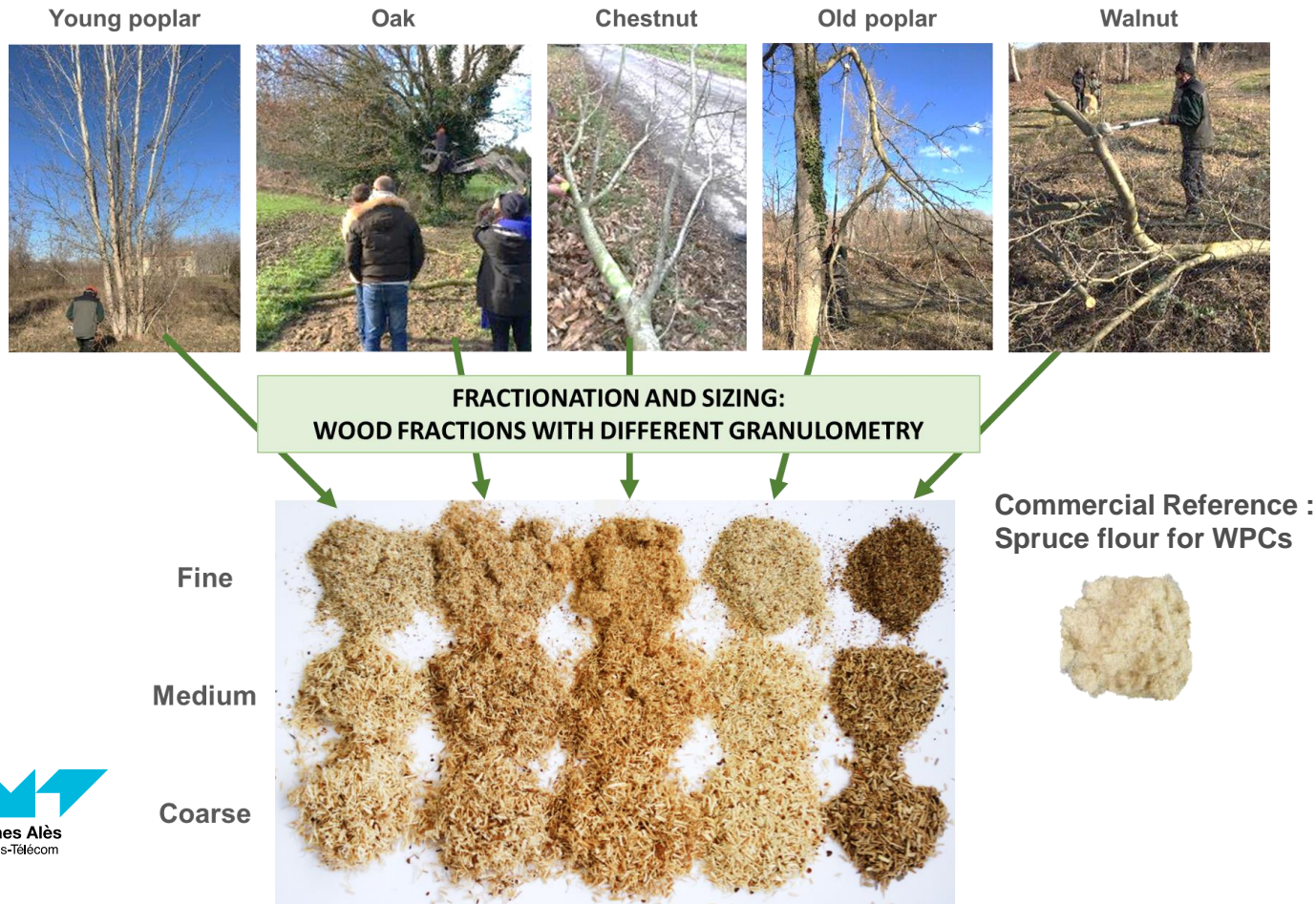
- ❑ Preparation & characterization of wood fractions
- ❑ Manufacturing of wood plastic composites (WPCs)
- ❑ Mechanical behaviour of composites
- ❑ Microstructural characterization of composites
- ❑ Processing / structure / properties relationships
- ❑ Towards the use of existing agroforestry feedstocks

# PREPARATION & CHARACTERIZATION OF WOOD FRACTIONS

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## Sourcing, fractionation & sizing

- **Collected branches** of different tree species in **agroforestry sites** (Gard, Brittany)
- **Fractionation and sizing at FRD lab** through well controlled impact and shear milling and sieving procedures





# PREPARATION & CHARACTERIZATION OF WOOD FRACTIONS

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## Sourcing, fractionation & sizing

### ▪ Bocage wood from 3 recovery platforms in Brittany :

Pluvigner (B1)

→ oak, chestnut + hazelnut, holly, cherry, birch

Mellac (B2)

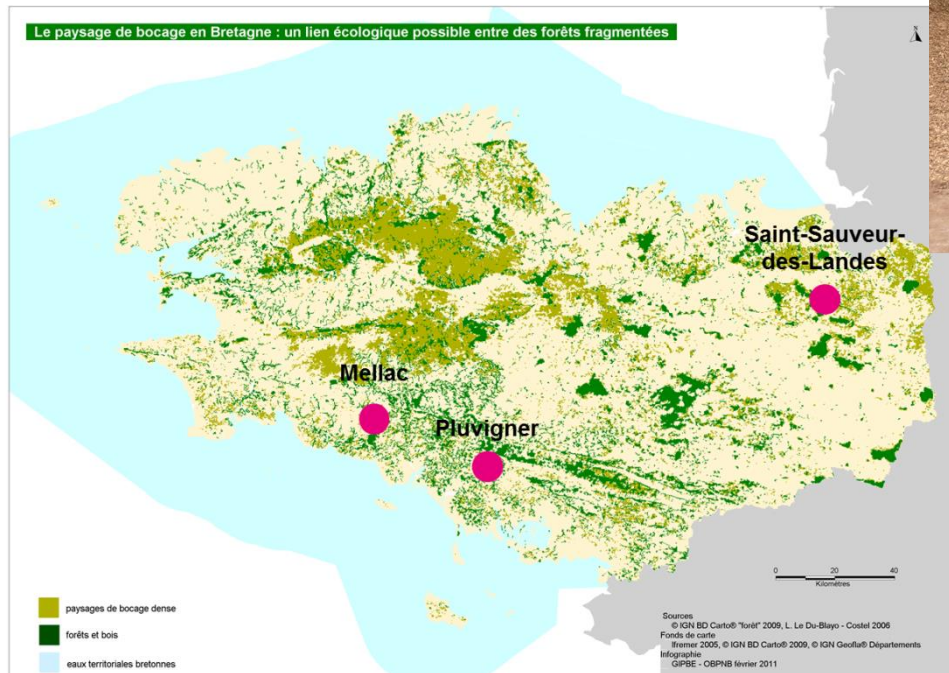
→ oak and chestnut

Saint-Sauveur-des-Landes (B3)

→ mainly composed of chestnut and also oak

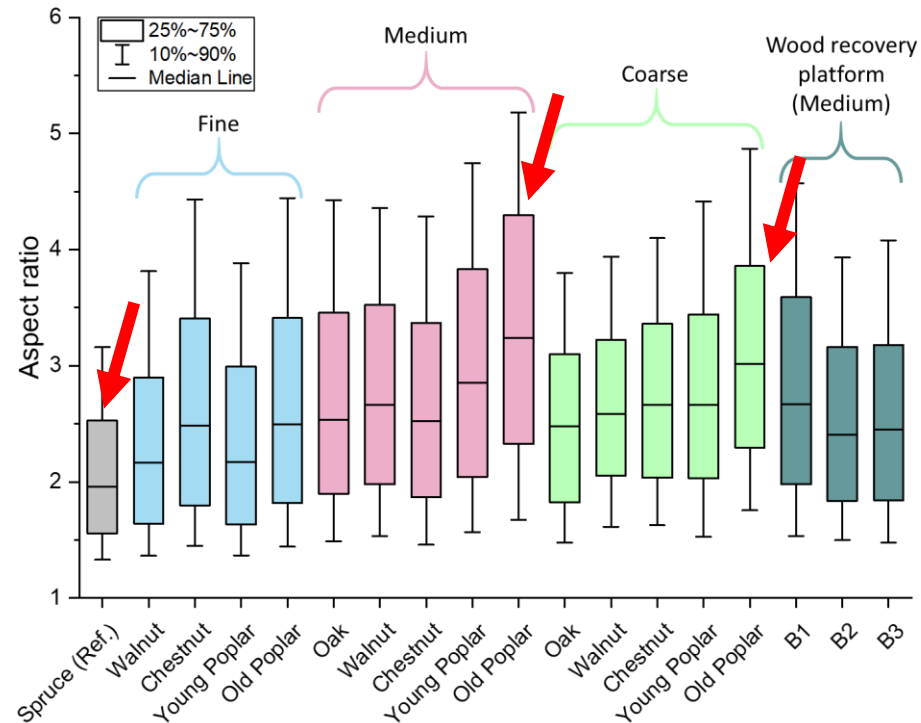
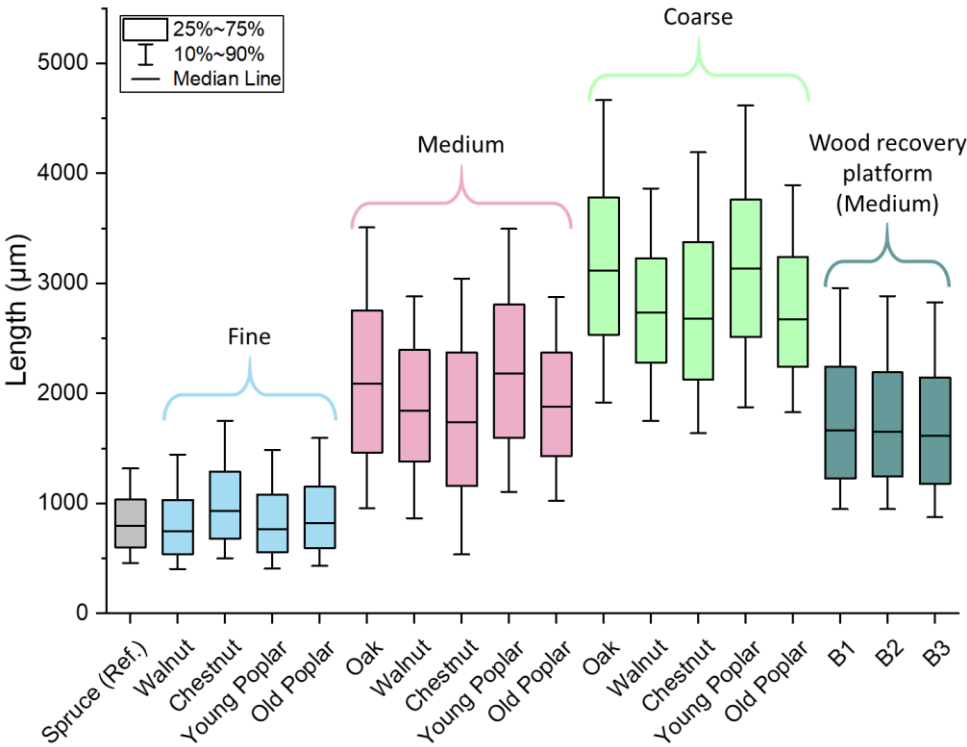


## Medium Granulometry



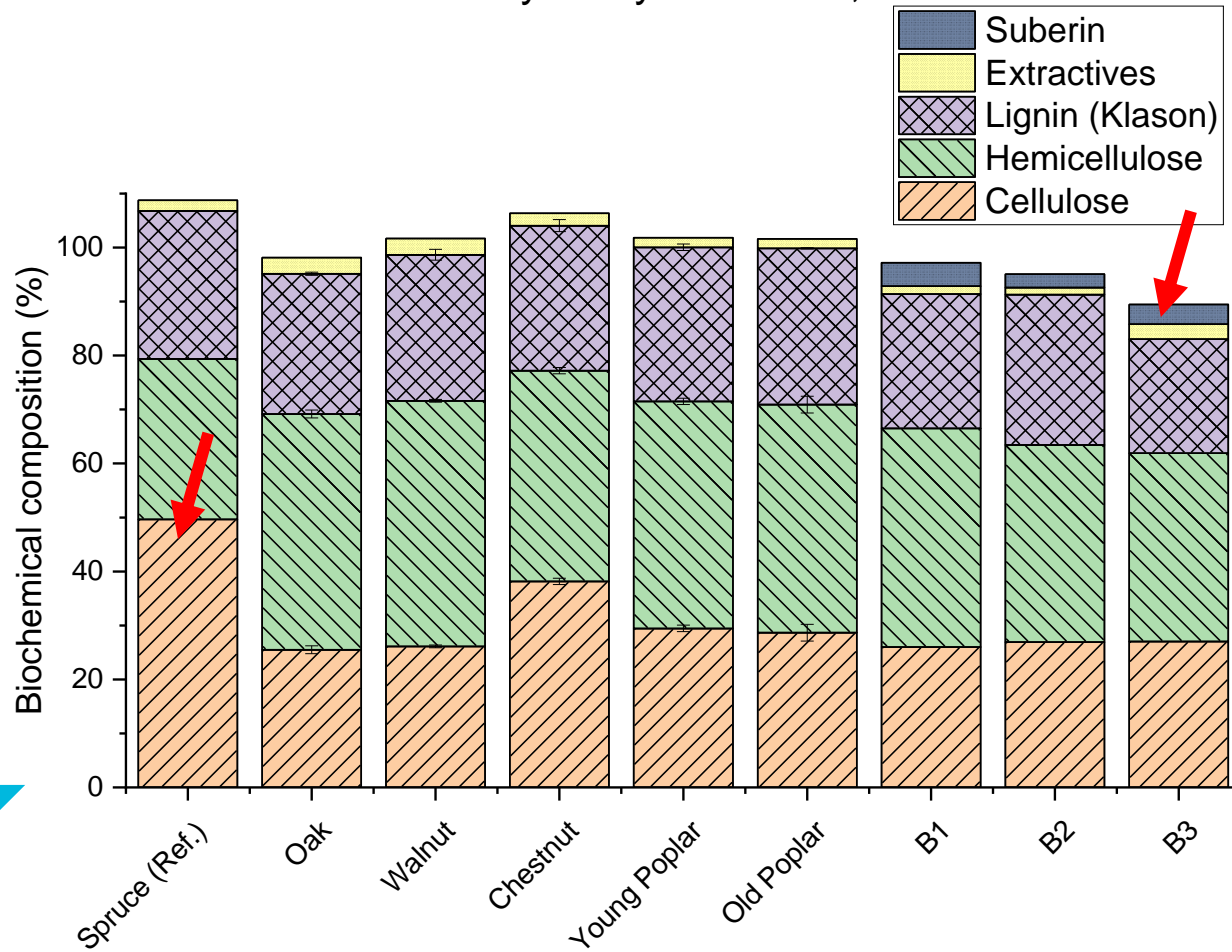
## Granulometry (FRD)

- **3 distinct fractions** in terms of **initial length**, regardless of wood species
- No significant effect on the initial aspect ratio AR  
(except lower AR for spruce and slightly higher AR for old poplar medium and coarse)



## Biochemical composition (LERMAB)

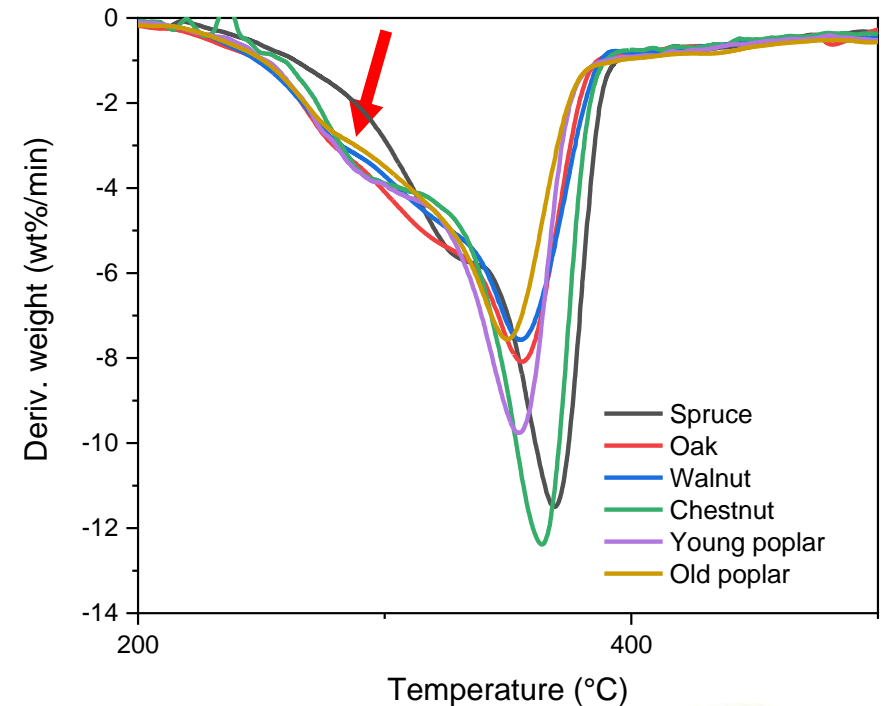
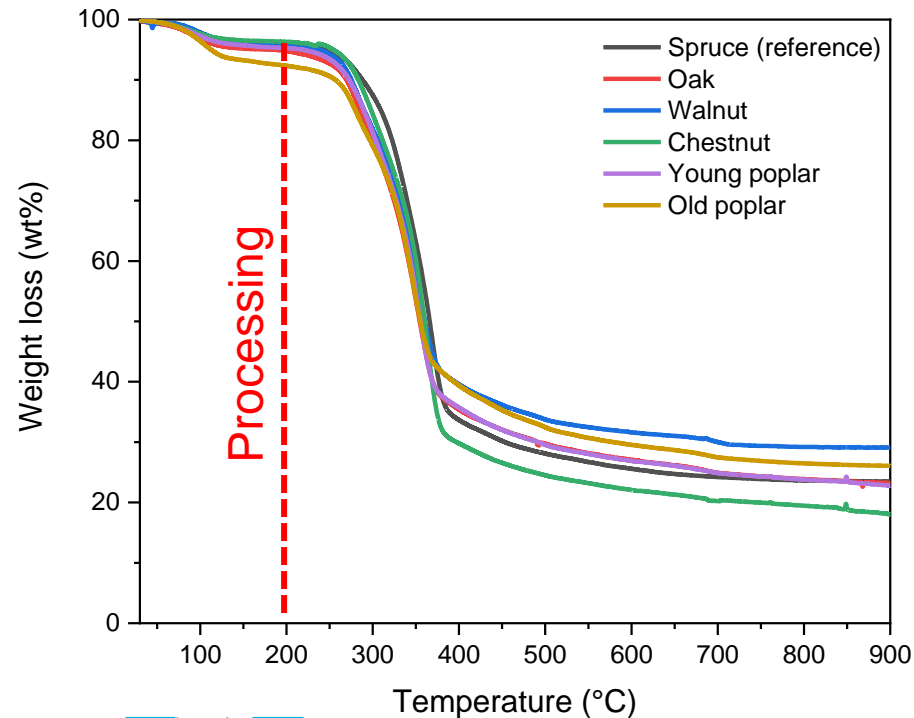
- **Less cellulose (~ 30%) and more hemicelluloses (up to 40%) for wood branches and wood from recovery platforms**
- **Similar amounts of lignin / extractives**
- **Suberin** was also found but only analyzed for B1, B2 and B3



## Thermal stability

Variations in thermal stability of agroforestry wood fillers :

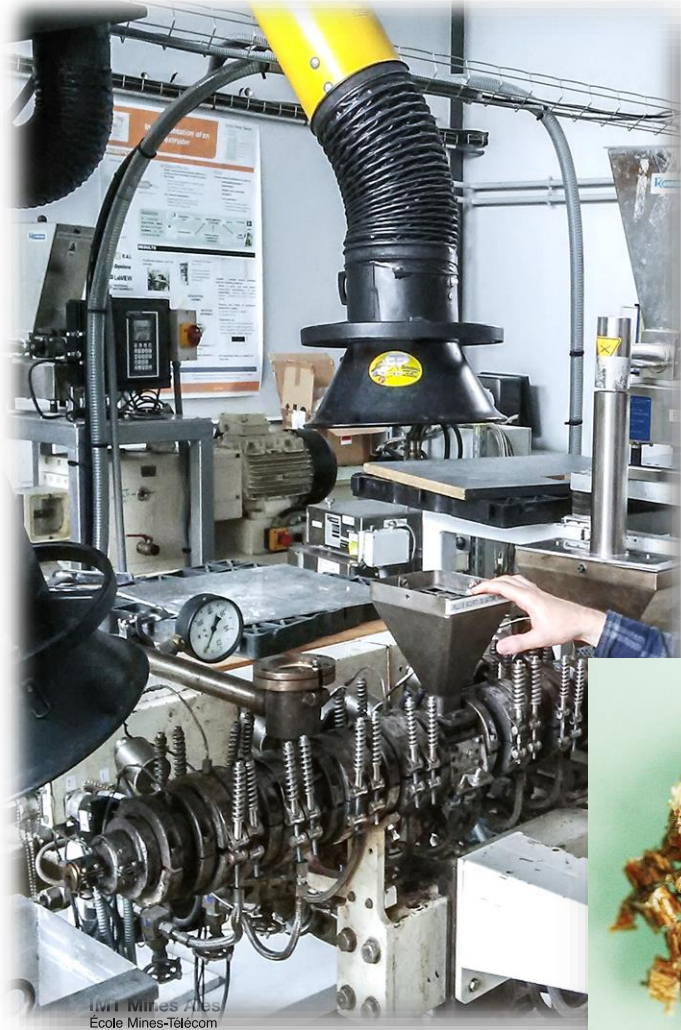
- **Degradation** mostly occurs **above processing temperatures**
- Reference (Spruce) and chestnut show **higher thermal stability** due to **lower hemicelluloses contents**



- ❑ Preparation & characterization of wood fractions
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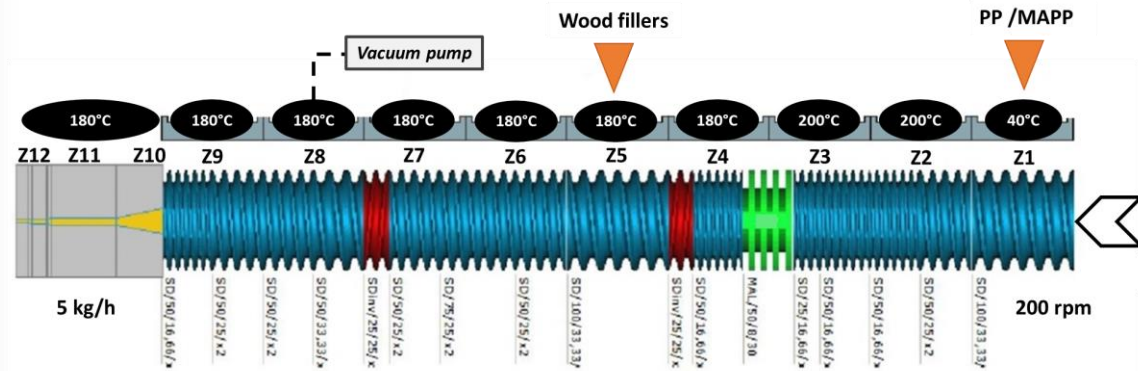
## Compounding by twin-screw extrusion

### TWIN-SCREW EXTRUSION



UMI Mines-Tes  
Ecole Mines-Télécom

### Extrusion parameters:



**PP 65%<sub>w</sub>**  
**PP-g-MA 5%<sub>w</sub>**  
**Wood fillers 30%<sub>w</sub>**

## Injection moulding

### INJECTION MOLDING



### Injection parameters:

- Pressure 800-950 bar
- Speed 120 rpm
- Melt temperature 180°C
- Mould temperature 30°C

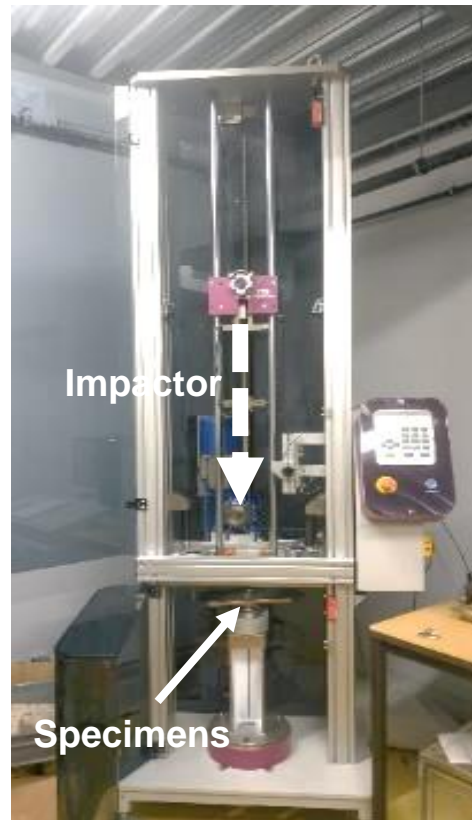


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## Mechanical tests

Tests	Property	Measured parameter
<b>Charpy impact</b>	Toughness	Resilience
<b>Tensile</b>	Stiffness	Young's modulus
	Strength	Maximum strength
	Ductility/ Fragility	Breaking strain



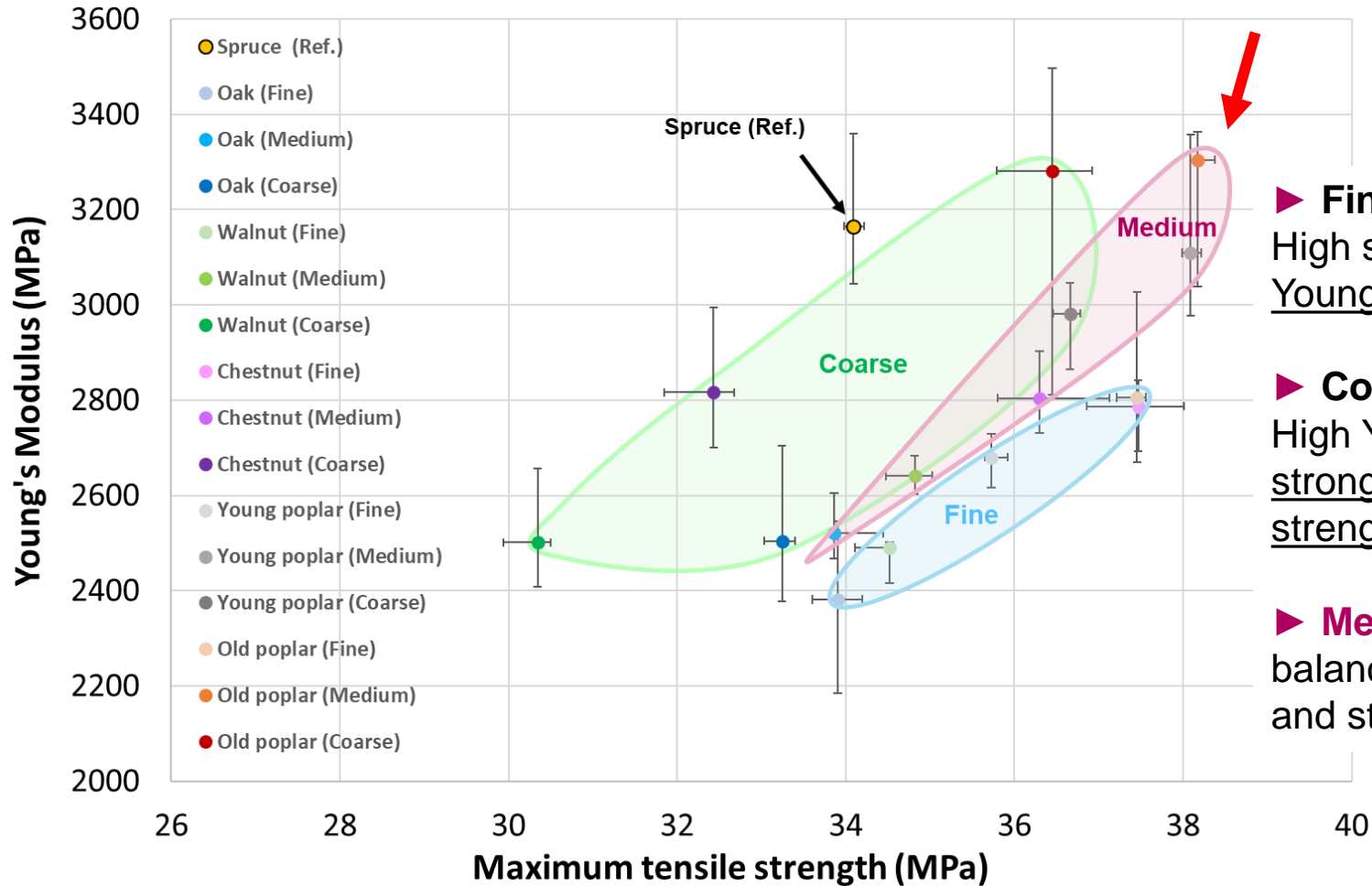
*Drop tower - Impact tests*



*Tensile machine*



## Effect of granulometry on tensile properties

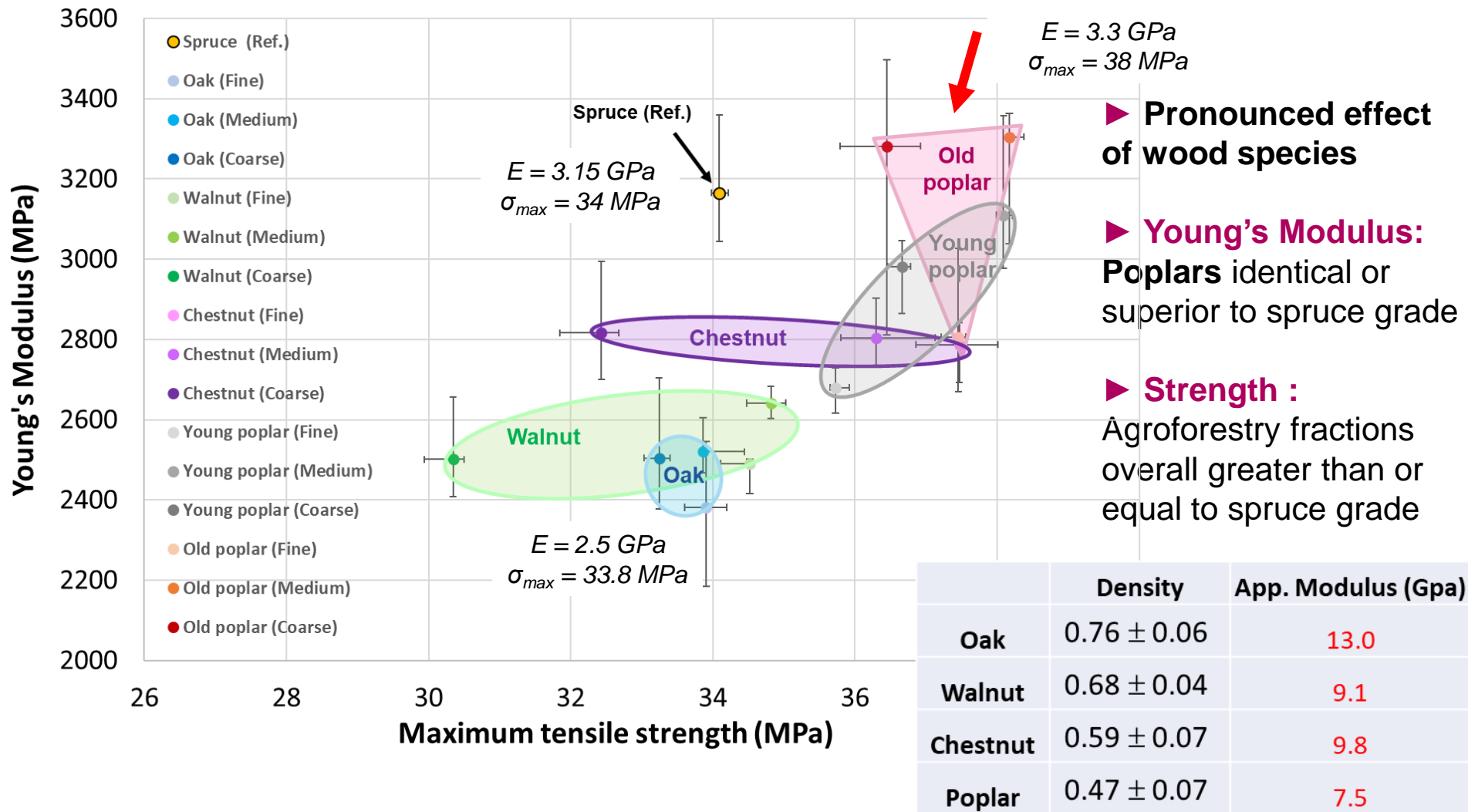


► **Fine :**  
High strength but low  
Young's modulus

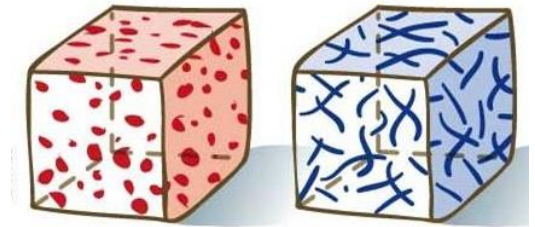
► **Coarse :**  
High Young's modulus but  
strong decrease in  
strength

► **Medium :** good  
balance between stiffness  
and strength

## Effect of wood species on tensile properties



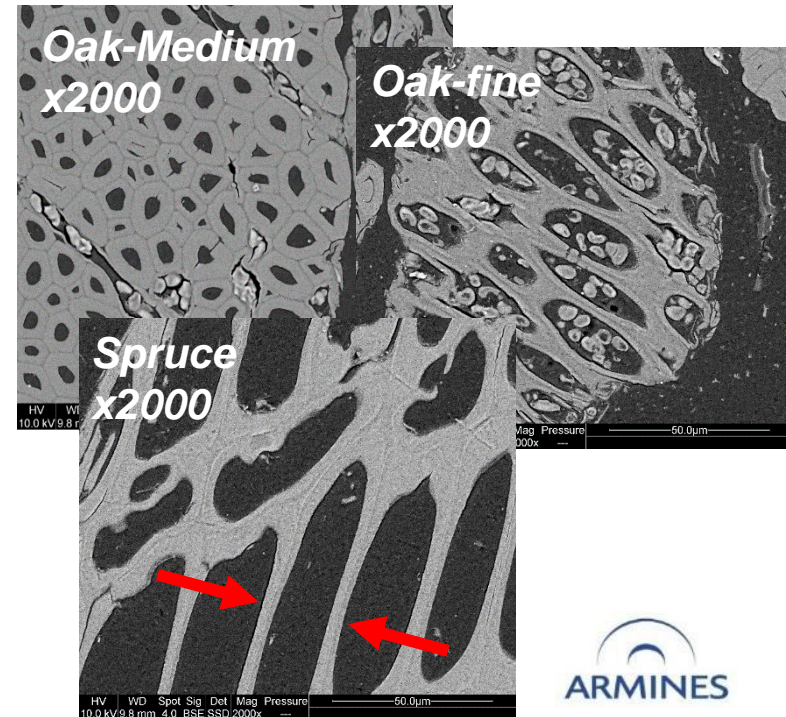
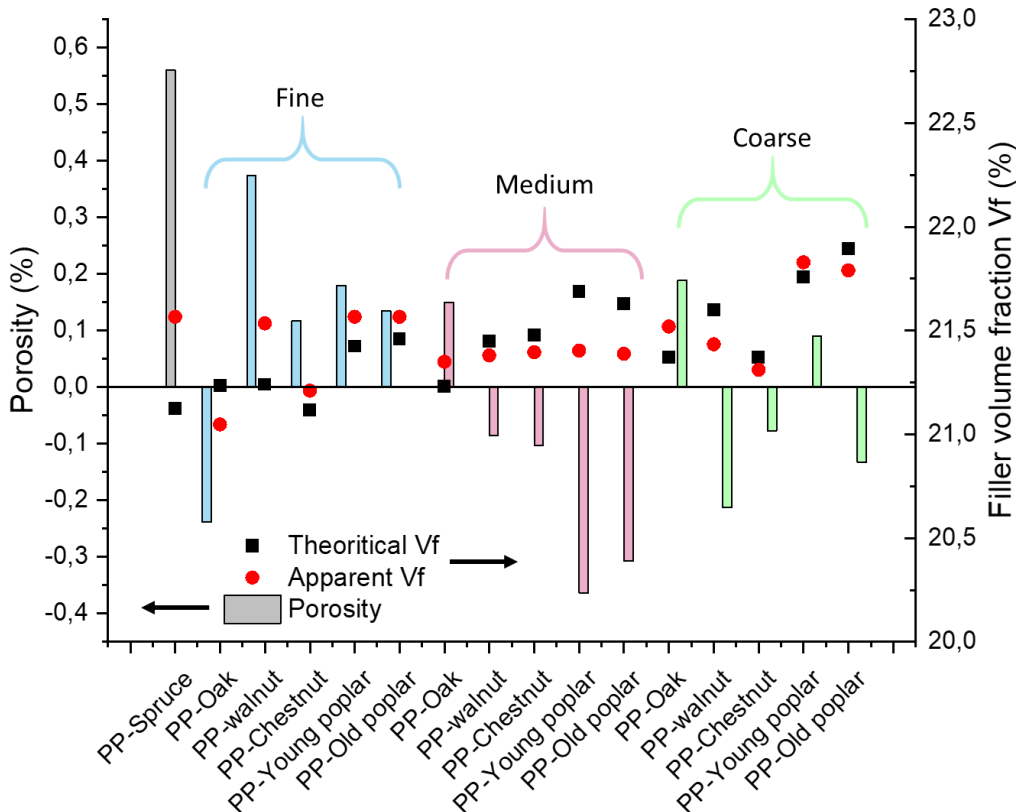
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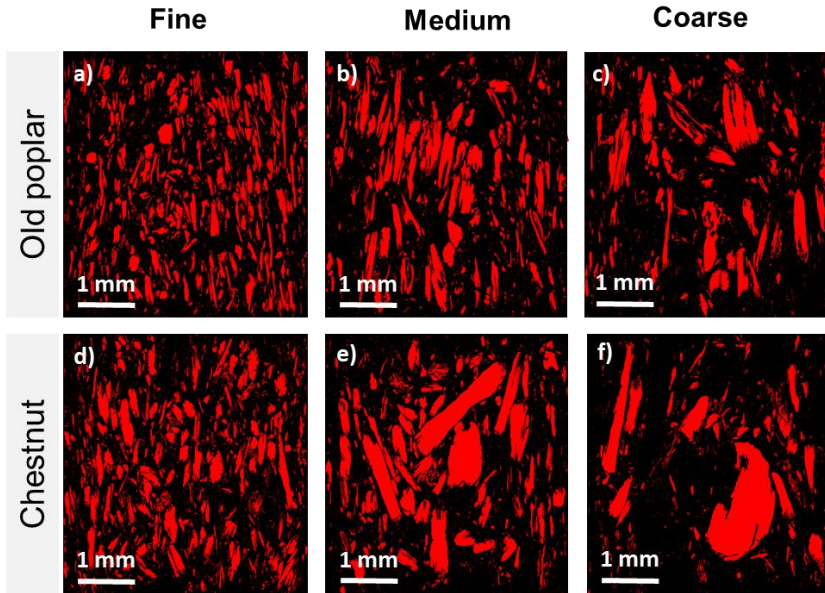
## Composite density and filler volume fraction

Wood species	Apparent density g/cm <sup>3</sup> (Tropix, CIRAD / data Agrobranche project)
Spruce	0.45
Oak	0.76 ± 0.06
Walnut	0.68 ± 0.04
Chestnut	0.59 ± 0.07
Poplar	0.47 ± 0.07

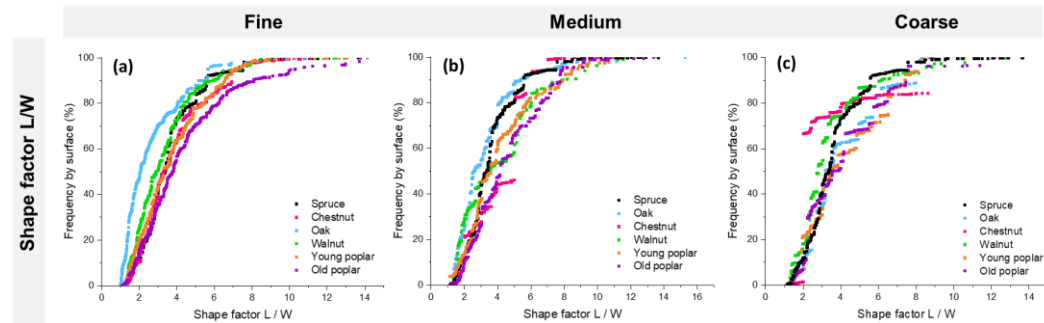
- Low porosity (med. 0.0065 %; min. -0.36%; max. 0.56 %)
- Independent of the granulometry and wood density
- **Lumens filling** by the polymer and/or **collapse of the cells** during injection molding



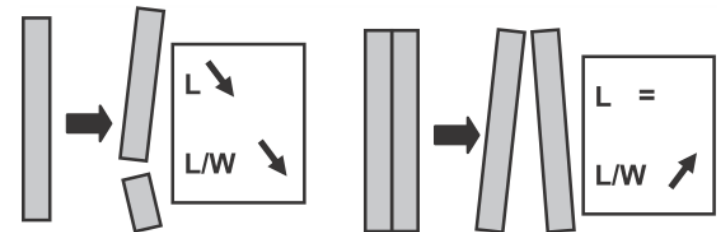
## Filler size and shape distributions



*Image analysis on SEM cartography of polished composite surface*



- **Great variations in L/W ratio** within the composites despite similar initial granulometry
- e.g. for medium granulometry : Poplar (4.2) > Chestnut > walnut > spruce > oak (2.6)

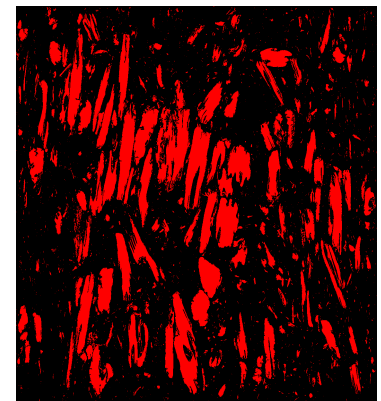
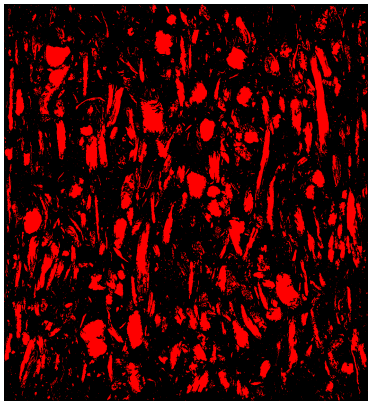
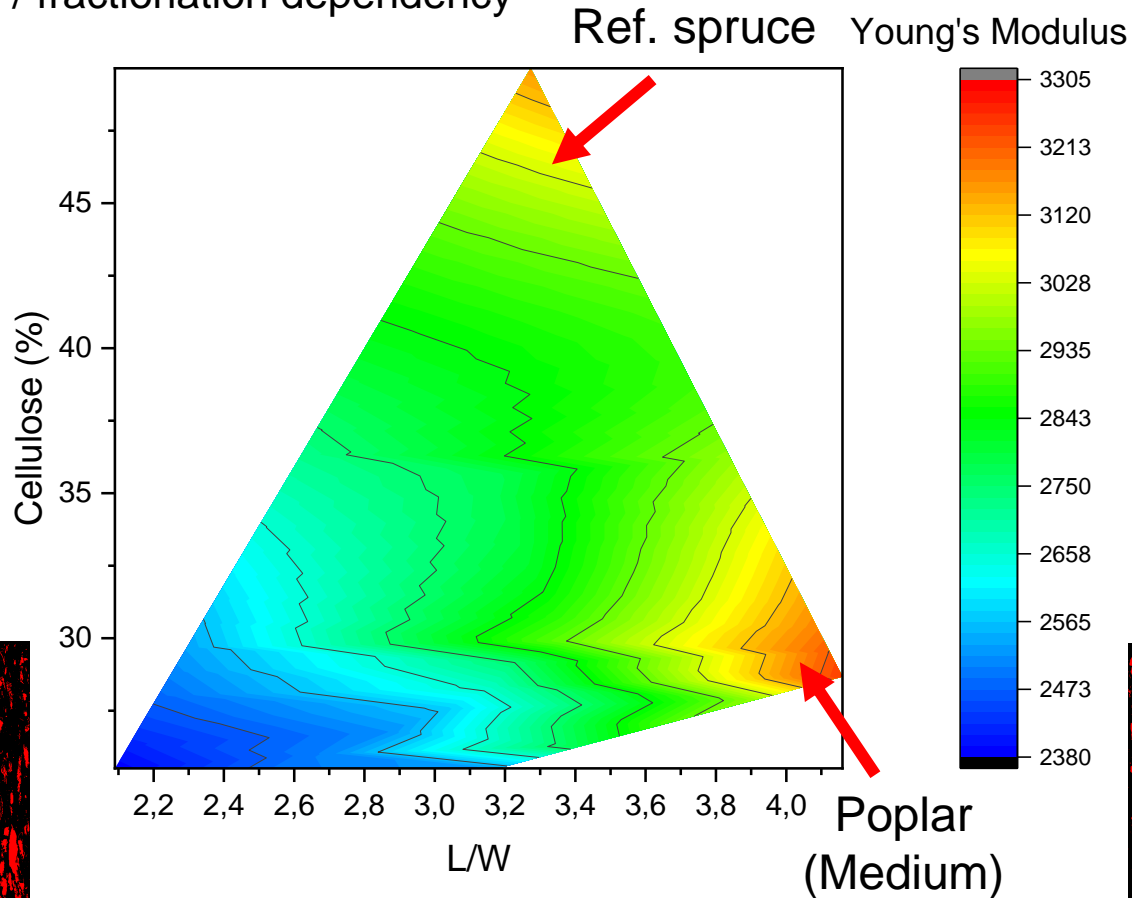


- **Contrasted breaking behaviour** during compounding
- Influence on mechanical properties: prediction (e.g.: Halpin–Tsai model)?

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## Effect of biochemical composition / Filler shape

- High cellulose content and/or high aspect ratio (L/W) improve composite's stiffness
- Wood species / fractionation dependency



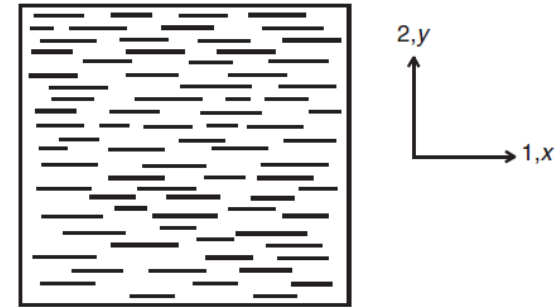
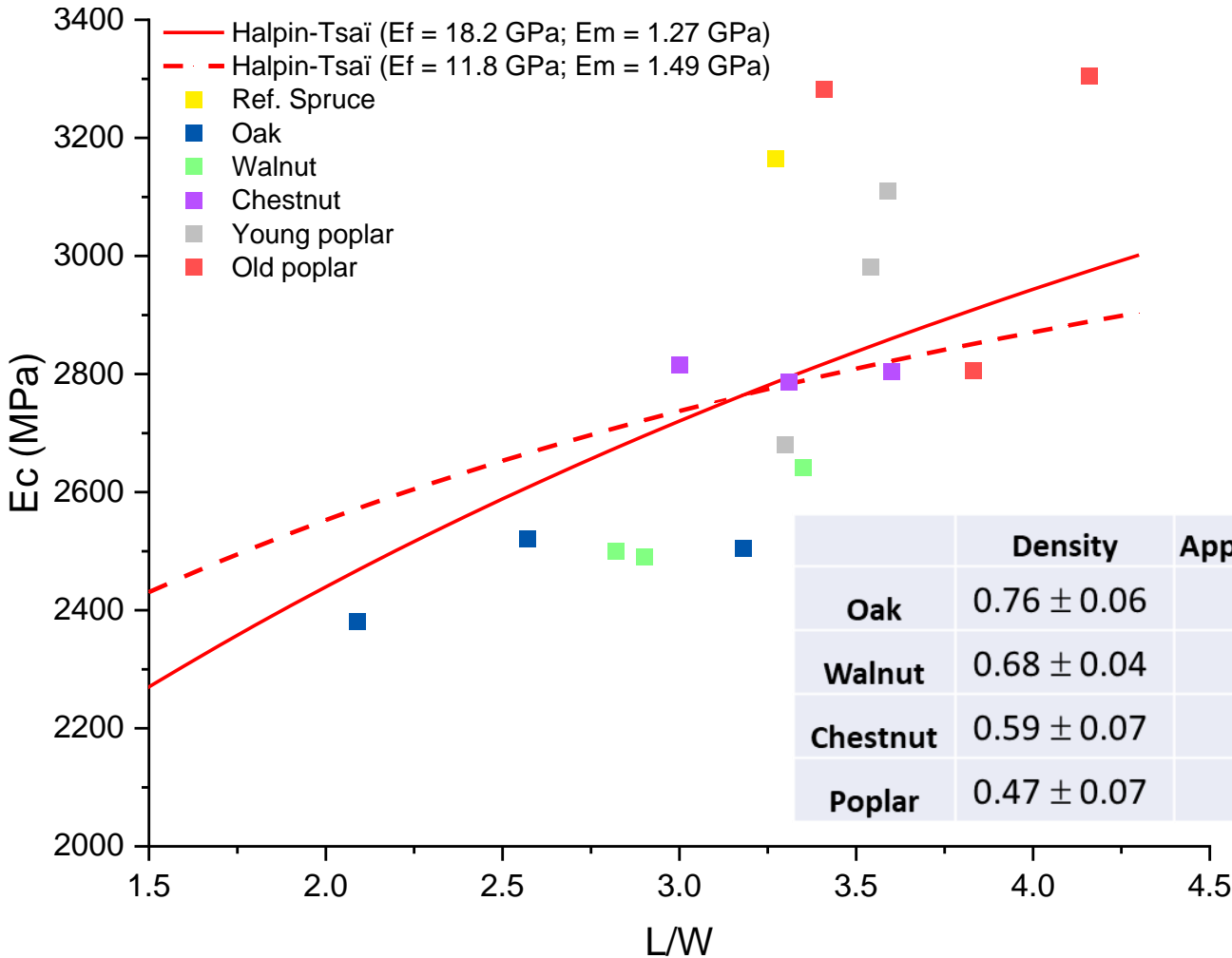


## Modeling the influence of filler shape (L/W) on elastic modulus

- Back calculation of the filler modulus with anisotropic Halpin-Tsaï model
- Equivalent filler / cell walls modulus between **11.8 and 18.2 GPa**

$$E_{11} = \frac{1 + 2(l_f/d_f)\eta_L v_f}{1 - \eta_L v_f} E_m,$$

$$\eta_L = \frac{(E_f/E_m) - 1}{(E_f/E_m) + 2(l_f/d_f)}$$

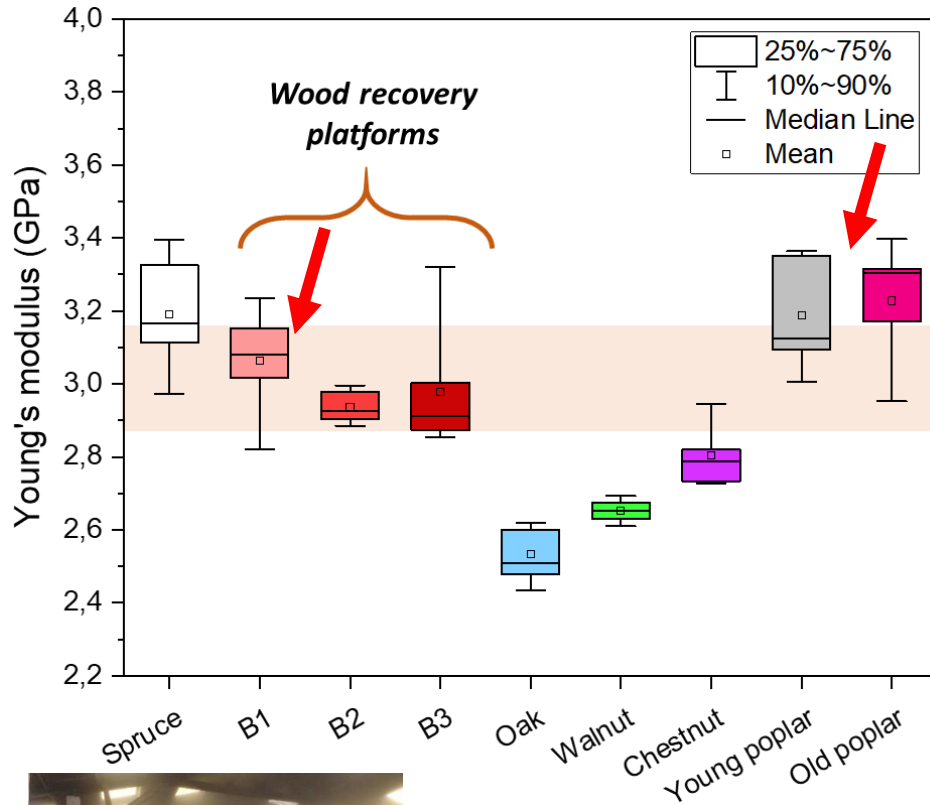


	Density	App. Modulus (Gpa)	cell wall Modulus (Gpa)
Oak	0.76 ± 0.06	13.0	17.1
Walnut	0.68 ± 0.04	9.1	13.4
Chestnut	0.59 ± 0.07	9.8	16.6
Poplar	0.47 ± 0.07	7.5	15.9

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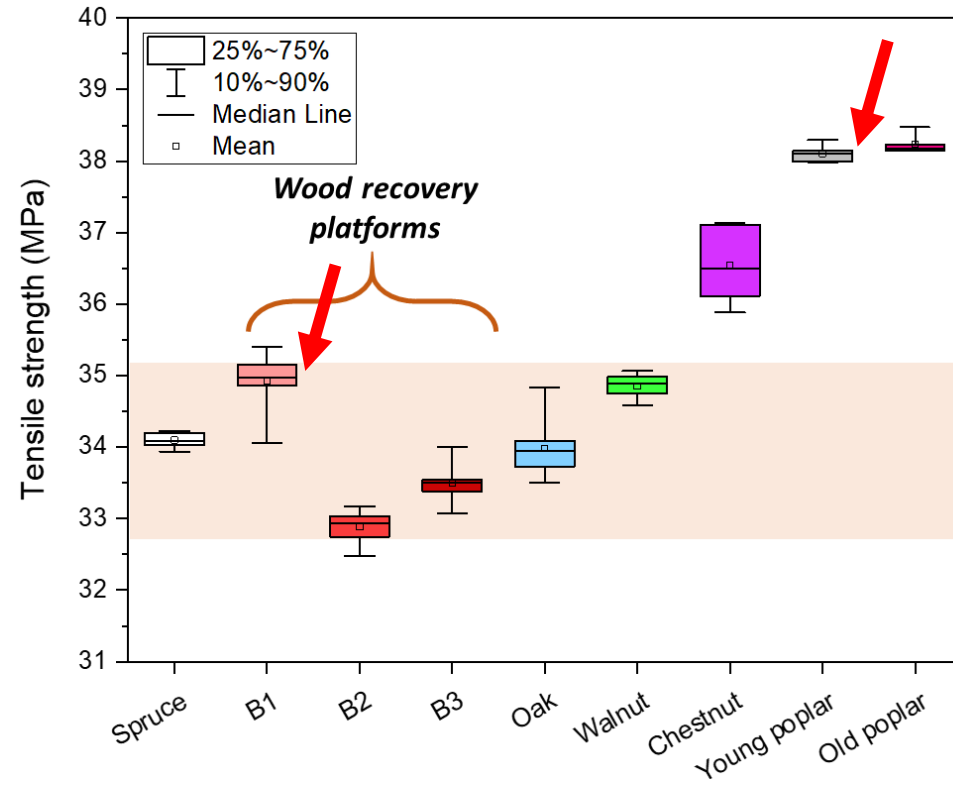
# TOWARDS THE USE OF EXISTING AGROFORESTRY FEEDSTOCKS 27

## Tensile properties



For medium granulometry

➤ **Similar stiffness and strength as commercial spruce grade**



## ➤ Main Results:

- Microstructure and resulting **mechanical behaviour** of the composites are **highly species and granulometry dependent**, up to 60% variation in mechanical performance (tensile and impact) !
- **Agroforestry** wood branches are **relevant as wood fillers for WPCs**

## ➤ Outcomes:

- **Definition of wood species and fractionation routes** to optimize composite mechanical performance in **relation with wood structure** (anatomy, morphology, cell wall composition)
- **Quality label for wood and wood-based products** issued from agroforestry

## ➤ Perspectives:

- Validate the potential of **existing agroforestry wood recovery platforms** (mixed species) in a demonstration-case production
- Study the effect of **intraspecific variability and age of wood trees**

# MERCI POUR VOTRE ATTENTION

## Agrobranche

Etude de la valorisation des branches en agroforesterie pour les filières matériaux et chimie biosourcés.

2018 2022



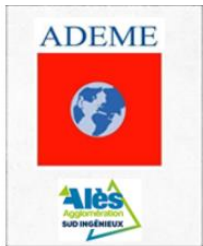
Coordination : Agroof SCOP

Contact : Fabien Liagre - liagre(@)agroof.net - 04 66 56 85 47

Mots-clés : Agroforesterie, branche, matériaux biosourcés, fibres végétales, molécules, chimie, produits biosourcés

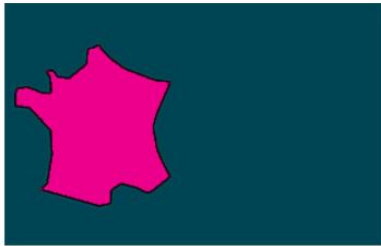
Projets en lien : Arbratouille

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FINANCEURS

001



LOCALISATION

002



PARTENAIRES

003



POSTER de présentation

004



POSTER du 5e Congrès mondial d'agroforesterie

005



RAPPORT Le rapport final

## ➤ Articles:

- DOINEAU E., RABATEL J., GALLARD B., RIVARD P., DUBORPER A., TERRASSE F., CANDELIER K., MARCHAL R., DAY A., DUMARCAY S., GERARDIN P., BEIGBEDER J., CORN S., LIAGRE F., LE MOIGNE N. Towards sustainable wood fillers from agroforestry for wood-plastic composites: effect of filler size and wood species. Under preparation, to be submitted to Industrial crops and Products in 2024

## ➤ Posters:

- LIAGRE F., MARTIN CHAVE A., LE MOIGNE N., CORN S., MARCHAL R., BOUTAHAR N., CHAHINEZ A., SÉNÉGAS I. LE PORT S., GÉRARDIN P., RIVARD P., BONO P. Poster L09.P05, Session “Value Chain”, p 288, Book of Abstracts of the 4th World Congress on Agroforestry, 20-22 May 2019, Montpellier France, 888 pages.
- RABATEL J., GALLARD B., RIVARD P., LIAGRE F. D, BEIGBEDER J., CORN S., LE MOIGNE N. Valorisation des fibres lignocellulosiques issues de l'agroforesterie dans le domaine des composites bois-polymers influence de l'essence et de la granulométrie. 16 èmes journées scientifiques et industrielles du Groupe Français des Polymères (GFP), Mars 2020, Alès, France.
- DOINEAU E., RABATEL J., GALLARD B., RIVARD P., DUBORPER A., DAY A., DUMARCAY S., GERARDIN P., BEIGBEDER J., CORN S., LIAGRE F., LE MOIGNE N. Towards sustainable wood fillers from agroforestry for wood-plastic composites: effect of filler size and wood species. EPNOE 2021 - 7th EPNOE International Polysaccharide Conference, Oct 2021, Nantes, France.
- LIAGRE F., LE MOIGNE N., DOINEAU E., RABATEL J., BEIGBEDER J., CORN S., DUBORPER A., DAY A., DUMARCAY S., GERARDIN P., BÉRAL C. Agrobranche Project : Towards sustainable wood fillers from agroforestry for WPC. Abstract approved for a poster presentation in person – International Agroforestry Congress Quebec – Canada July 2022.