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► **To cite this version:**

Muritala Arowolo, Wiyao Azoti, Bruno Castanié. Modelling of mechanical properties of plant fibres reinforced composite materials. 3<sup>ème</sup> Conférence sur les Eco-Matériaux en Afrique – CEMA'2024, Jun 2024, Libreville, Gabon. hal-04630326

**HAL Id: hal-04630326**

**<https://hal.science/hal-04630326>**

Submitted on 1 Jul 2024

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## Modélisation des propriétés mécaniques des matériaux composites à fibres végétales

### *Modelling of mechanical properties of plant fibres reinforced composite materials*

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#### 1. Introduction

The demand for sustainability makes natural fibres gain attraction in composite materials. Among natural fibres, plant fibres are mainly used as bio-fibres in natural fibre-reinforced polymer composites (NFRCs) [1] due to their low processing costs and wide availability [2] [3]. Integration of plant fibres as a composite polymer reinforcement is a suitable alternative for replacing petroleum products (E-glass fibres, for example), which strongly contribute to global warming [4].

To fully take advantage of such composites, the properties of the fibres and the matrix should be characterised either by experiments or numerically using predictive models. The latter, i.e predictive models, are relevant tools for cheap, fast and reliable virtual analyses of mechanical behaviours. For instance, modelling using micromechanics enables the determination of a heterogeneous material's macroscopic properties by analysing its microstructure. The Eshelby inclusion [5] problem and the selection of a representative elementary volume (RVE) offer a cheap and time effective means to study complex composite materials. Besides, finite element modelling of RVE represents a full field method that helps model the aspect ratios (ARs), shapes, orientations (aligned/random) of reinforcements in composites.

In this work, both micromechanics and RVE modelling are used to study plant fibres reinforced thermoplastic matrix (polypropylene) composites. For such a purpose, the RVE is obtained for different aspect ratios ( $L/d$ ) of fibres along with fibre orientations (aligned/random). The mechanical properties are obtained for four plant fibres, mainly: flax, vegetal-technic, wood-force and a hybrid of flax and vegetal-technic. Numerical results dealing with random orientation are validated with respect to the experimental work by Barteau et al. [4].

#### 2. Materials and methods

Four plant reinforcements are investigated in this work. Their mechanical and morphological properties are summarised in Table 1. The matrix, which is considered as isotropic, is a polypropylene (PP) polymer. Its Young modulus  $E_m$  and Poisson's ratio  $\nu_m$  are given, such as  $E_m=1576$  MPa,  $\nu_m=0.36$ .

##### 2.1 Numerical modelling of RVE

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Typical RVEs (aligned and random oriented fibres) are investigated in Figure 1, in accordance to the aspect ratios and volume fractions of the fibres. Then, periodic boundary conditions are prescribed on the RVE with respect to whether a shear or normal load is of interest.

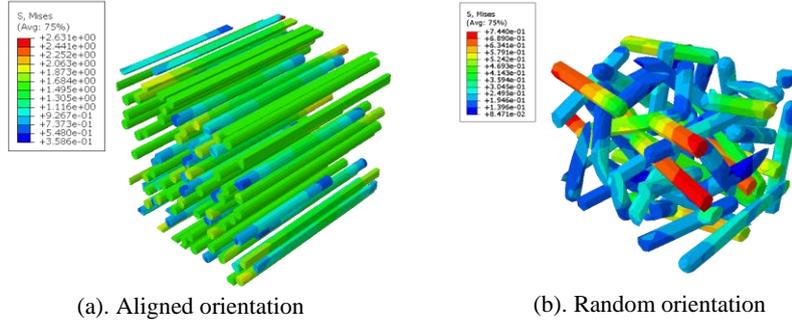


Fig. 1. Contribution of fibre orientation to the global stress of an RVE

Tab. 1: Mechanical and morphological properties of plant fibres [4]

Reinforcements	Fibre length LEFI (μm)	Fibres diameter DIFI (μm)	Aspect ratio L/D	Elastic modulus E (GPa)	Poisson ratio
Flax	1,021 ± 737	27.2 ± 14.6	37.5	52.5	0.4
Vegetal Technic	979 ± 322	107.4 ± 38.0	9.1	30	0.3
WoodForce	727 ± 572	42.0 ± 42.1	17.5	25	0.3
Hybrid (Flax/Vegetal Technic)	745 ± 625	40.4 ± 32.6	18.5	41.25	0.4

## 2.2 Micromechanics formulation

Using a scale transition method, the effective properties of a composite material are obtained using an RVE. The scale transition establishes the relationship between the microscale (local) and macroscale (global) elastic properties. It consists firstly in the localisation step by deriving the global strain concentration tensor  $\mathbf{A}^I$ . Then, the homogenisation step uses averaging techniques to approximate the effective stiffness tensor of the RVE such as:

$$\mathbf{c}^{MMT} = \sum_{I=0}^N v_I \mathbf{c}^I : \mathbf{A}^I = \mathbf{c}^0 + \sum_{I=1}^N v_I (\mathbf{c}^I - \mathbf{c}^0) : \mathbf{A}^I \quad (1)$$

In equation (1),  $\mathbf{c}^0$  represents the elastic stiffness tensor of the matrix while  $\mathbf{c}^I$  is that of the inclusion. The variable  $v_I$  denotes the volume fraction of the inclusion. The tensor  $\mathbf{A}^I$  states for the global strain concentration tensor. Its expression is given such as [6]:

$$\mathbf{A}^I = \boldsymbol{\zeta}^I : (\bar{\boldsymbol{\zeta}}^I)^{-1} \quad (2)$$

$$\boldsymbol{\zeta}^I = (\mathbf{I} + \mathbf{T}^{II} : (\mathbf{c}^I - \mathbf{c}^R))^{-1} \quad (3)$$

with  $T^{IJ}$  representing the interaction tensor between inclusions within the RVE. It is expressed such as:

$$T^{IJ}(c') = \frac{1}{v^I} \int_{v^I} \int_{v^J} \mathbf{F}(r - r') dV' dV \quad (4)$$

In equation (4),  $\mathbf{F}$  is the so-called modified Green tensor given by:

$$\Gamma_{mni j}(r - r') = -\frac{1}{2} \{G_{mi, nj'}(r - r') + G_{ni, mj'}(r - r')\} \quad (5)$$

with  $G_{mi}$  standing for the components of the Green's tensor.

### 3. Results and discussions

Numerical results in Figure 2, are obtained for a flax volume fraction  $v_f = 0.2$ . The Young modulus for random orientation shows a good agreement between numerical and analytical as well as experimental results. A maximum relative error of approximately 7.4% is found between numerical and experimental results. This variability is attributed to the level of randomness of the RVE compared to experimental SEM analysis by Barteau et al. [4]. It is worth noticing that it is practically impossible to numerically replicate in the RVE the degree of randomness captured experimentally.

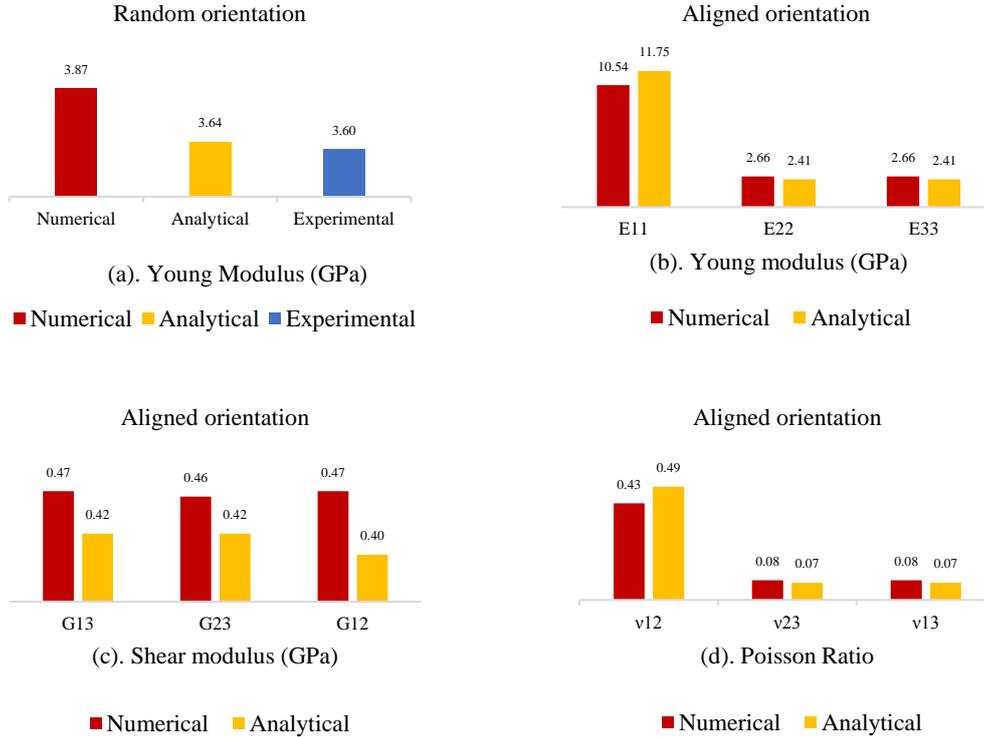


Fig. 2: Histogram of elastic modulus of flax fibre reinforced thermoplastic composite with  $v_f = 0.2$  and  $AR = 37.5$

Besides, aligned fibres reinforced thermoplastic PP composite have led to transversely isotropic behaviour. The effective Young modulus  $E_{11}$  is significantly dominated by the behaviour of the fibres while transverse  $E_{22} = E_{33}$  behaviour is governed by the matrix. The shear moduli  $G_{13}$ ,  $G_{23}$ , and  $G_{12}$ , numerically predicted show a slight high response than the analytical model. Finally, the Poisson's ratio gives a fair agreement between both approaches.

#### 4. Conclusions and perspectives

The mechanical properties of plant fibres reinforced composites were determined using a numerical RVE and a micromechanics approach. Random and aligned orientations, were analysed. For a flax volume fraction  $v_f = 0.2$ , the results in terms of Young's modulus for random orientation indicate a good agreement between both numerical and analytical results compared to literature data. Results obtained for aligned fibre orientation also show a good agreement between numerical and analytical approaches.

This work enables a quick derivation of the characteristics for an elementary composite ply as a function of the fibre volume fraction. As a perspective, it will lead to the development of plant fibre reinforced laminate composites at a mesoscale. Applications will be directed to crash box structures in the automotive industry.

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