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Relationships between 3D geometry and tensile behaviour of plant fibres: a numerical study based on anisotropic viscoelastic model

A. Del Masto[1*], F. Trivaudey[1], V. Guicheret-Retel[1], V. Placet[1], L. Boubakar[1]

[1] Department of Applied Mechanics, FEMTO-ST Institute, UMR CNRS 6174
University of Bourgogne Franche-Comté, F-25000 Besançon, France
* Corresponding author: Email: alessandra.del.masto@univ-fcomte.fr, tel: +33 (0)3 81 66 60 10

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Natural fibres derived from plants, such as hemp, flax and alfa fibres, are nowadays attractive candidates for replacing synthetic man-made fibres in reinforcing organic matrices in high performance composite applications. This use requires an accurate understanding of their mechanical behaviour and the development of robust models.
Experimental observations have clearly shown that most plant fibres are characterised by an intricate structure, morphology and organisation which make their characterisation more complex than for solid circular man-made fibres (*1*). Their geometry depends on their growing, harvesting and processing conditions and might exhibit large dispersions. These fibres have generally a complex rounded polygonal outer shape which is irregular and non-uniform along length of the fibre and also varies from one fibre to another (*2*-*3*). The central cavity can be narrow, round or elliptical, with a diameter depending of the plant maturity.
When compared to purely cylindrical geometry, it is possible that such geometric features could induce effects on the fibre mechanical behaviour including stress concentrations, non-linearities, buckling and mechanical coupling (twist). The randomness in plant fibres shape and the associated behaviour can also have a significant impact on the mechanical properties and behaviour of composites reinforced with such fibres.
Most of the models of plant fibres consider the fibre as a thick-walled cylinder made of an isotropic elastic material (*4*-*5*). Non circular cross-section and the possible variation of the cross-section along the fibre length are generally not taken into account in the current models.

So, the aim of this study is to model and analyse the influence of much more complex geometries on the tensile behaviour of plant fibres.

The macroscopic 3D model used in this study is based on a previously developed model (*6*). The fibre wall is considered as an orthotropic composite material with long fibres (corresponding to the cellulose microfibrils) having a helical orientation with a viscoelastic constitutive law describing finite transformations through a material rotating frame formulation. The possible variations in cellulose microfibrils orientation along the fibre length are also taken into account in this modelling approach. This constitutive law was implemented in Abaqus® FEM software.
Concerning the fibre geometry, real and simplified cross-section shapes were considered. The determination of the 3D shape of the plant fibres still remains a challenge. The difficulty comes generally from the size and fragility of elementary fibres. So, as a starting point of this study, a real cross section shape of a hemp fibre has been used for numerical simulation. The contour lines of the external shape of a fibre and its lumen were determined using microscopic optical picture and pattern recognition tools. The 3D geometry is then obtained by extrusion of the external contour and implemented in the Abaqus® software. Results of numerical simulation show that the irregularities of the morphology do not highly affect the global tensile behaviour of the fibre, but they do have an influence on the apparition of stress concentration, and so on the rupture behaviour. The analysis of the rupture phenomena is beyond the scope of this study, so we propose, in a first approach, to investigate the influence

of non-unity transverse aspect ratios of particular simplified morphologies (non-circular cross-section as shown in Fig.1) on the global tensile behaviour of the elementary fibre. The aim is, in particular, to investigate the influence of the degree of ellipticity of the fibre section and its variation along the fibre length on its tensile behaviour.

The tensile stress-strain responses of the fibre were plotted in Fig.2 as a function of the ellipticity ratio (for different values comprised between 1 and 0.1). Results clearly show the strong influence of the fibre geometry on its tensile response and particularly on the shape of the non-linearity of the response. Geometric issues could explain the different types of tensile behaviour experimentally observed (*7*).

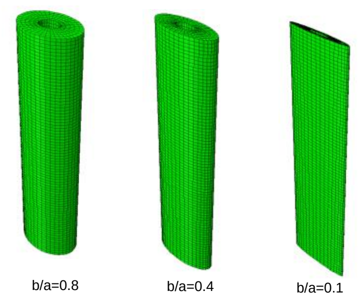

Figure 1: *Simplified geometries of the modelled fibres*

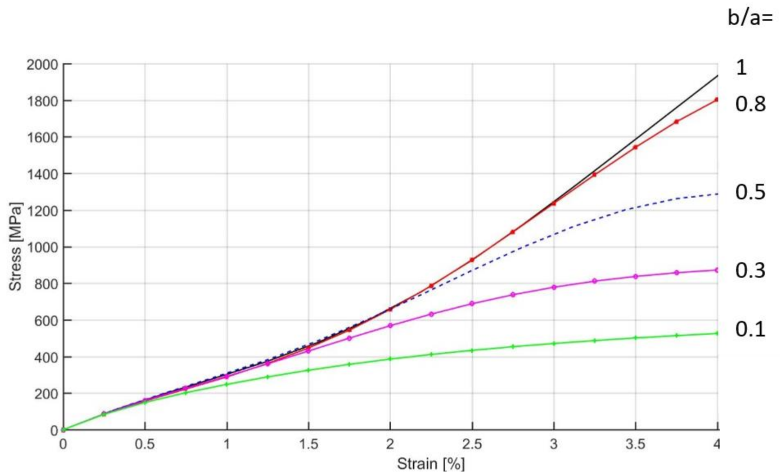

Figure 2: *Computed tensile stress-strain curves for different degrees of ellipticity*

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