Analytical description of biological fibrous tissue failure

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In the field of traumatology, human body Finite Element Models are used to predict injury occurence. This requires the development of constitutive laws to be integrated to these models.

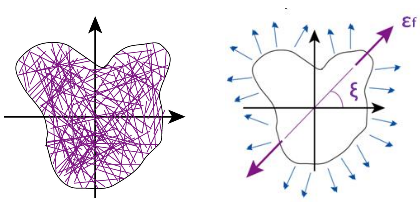
Many fibrous membranes can be found in the human body, like the skin or the capsule surrounding most of the abdominal organs. Liver in particular is surrounded by Glisson's capsule, made mostly of collagen fibers with more or less preferred directions (see Fig.1). Under impact, one of the failure types of the liver is surface laceration, which involves the capsule and the underlying tissue called parenchyma. Thus, predicting liver surface laceration first requires a model of fibrous tissue failure.

a) b)

Figure 1: a) Surface laceration on human liver - b) Histological section of human liver capsule (x40)

Among the previous studies focusing on fibrous tissue modeling, two main directions can be found: continuum models [1, 2] and models based on a microstructural representation of the fiber network [3, 4, 5, 6]. The second orientation makes it possible to follow the evolution of the structure (failure of fibers, failure of bonds between fibers, realignement, etc) and is a more precise and more general description of the tissue, but its compilation is time consuming. Most of the work done so far has focused on fibrous tissue elastic behavior.

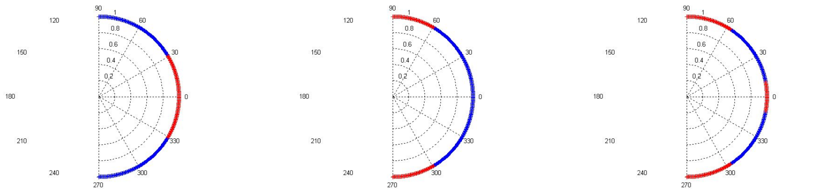
The present work aims at describing fibrous tissue failure with a homogeneous damage model. It is based on a microstructural representation of a $2-D$ tissue made of elastic fragile fibers with a maximum strain before failure of ε_r, whom angular distribution is constant or variable. This model links global strain load to the occurrence of fiber failure (see Fig.2) : the strain is supposed to be homogeneous in the tissue and each fiber bears a longitudinal strain of $\underline{n}.\underline{\underline{E}}.\underline{n}$ with $\underline{\underline{E}}$ the global strain tensor and $\underline{n}$ the unit vector in the fiber direction.



$$\underline{\underline{\mathbf{E}}} = \begin{bmatrix} E_1 & 0 \\ 0 & E_2 \end{bmatrix} = \begin{bmatrix} k.\varepsilon_r.\cos\varphi & 0 \\ 0 & k.\varepsilon_r.\sin\varphi \end{bmatrix}$$

Figure 2: Fibrous tissue, microstructural description of the fibrous tissue and macroscopic strain load

Describing the equivalent homogeneous damage model requires the determination of the elastic domain and its evolution during damage. $2-D$ yield surfaces, displaying the maximum shear strain for one fiber to break, are determined in the strain space, using this fiber-by-fiber calculation (see Fig.3). They show that while the tissue behavior is isotropic if the fiber angular distribution is constant, it becomes anisotropic as fibers break. Every damaging loading case implies therefore a different yield surface. Then, an analytical homogeneous model is proposed, describing the distorsion of the yield surface of the tissue, until its complete failure . Homogenization of the stress finally allows the determination of the constitutive law during damaging. It aims at skiping the microstructural part of the calculation and being integrated to an existing FE-model.



Case 1 $k = 1.2 / \varphi = 0$ | *Case 2* $k = 1.2 / \varphi = \pi/2$ | *Case 3* $k = 2.2 / \varphi = \pi/6$

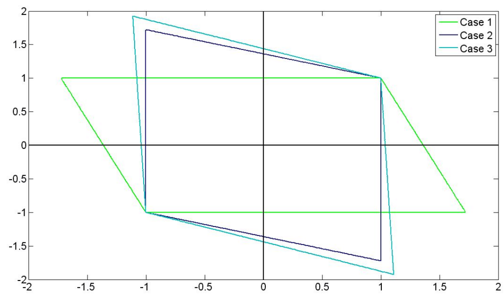


Figure 3: Distribution of broken fibers and corresponding yield surfaces - In blue: orientations of the unbroken fibers ; in red : orientations of the broken fibers.

To improve this model, further work will consist in enriching the fiber behavior description with a hyperelastic constitutive law, and adding phenomenons already included in behavior models from other authors : taking into account fiber bonds and their failure [7], including a matrix in the model and its relation to the fibers during damage (sliding, wrenching), considering fibers alignement [8, 9] and crimp [6] under loading.

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