Workshop « Soft Material Models »

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Phase field to model crack propagation in soft materials

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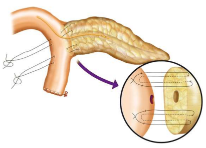
Abstract

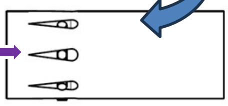
The prediction of damage and rupture in soft tissues has become a crucial task in medical monitoring and risk assessment of diseases. To this end, numerical simulation has emerged as a central helpful support tool for the medical community. This work develops a phase-field approach to model damage and fracture of soft tissues. The regularized crack surface is derived to overcome complexities of crack discontinuities. Next, the continuum variational formulation is developed. The numerical efficiency of the computational framework is established.

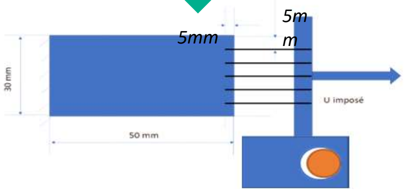
Methodology

1. Preliminary Experimental and numerical Device



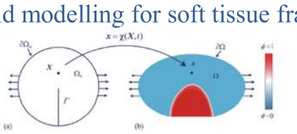
- The healthy part of the pancreas be sewn back on the intestine using polymer threads
- The threads exert compressive stresses at the level of contact with the tissues of the pancreas
- Intervention of fistulas in the tissues of the pancreas





Characterize and identify the hyperelastic behavior of the sample as well as the fracture behavior under the action of the wires.

2. Phase Field modelling for soft tissue fracture



(a) Schematic of an elastomer containing internal discontinuity surfaces in its initial configuration. (b) Phase field description of discrete cracks in the current configuration.

$$\underbrace{\prod(\mathbf{u},\phi)}_{\text{Internal Energy}} = \underbrace{\int_\Omega g(\phi)\psi_0(\mathbf{F})dV}_{\text{Elatic Energy}} + \underbrace{\int_\Omega G_c\gamma(\phi,\nabla\phi)dV}_{\text{Crack Surface Energy}} + \underbrace{\frac{\eta}{2}\int_\Omega (\frac{\partial\phi}{\partial t})^2 dV}_{\text{Dissipation Energy}}$$

- **Newton–Raphson Algorithme**:

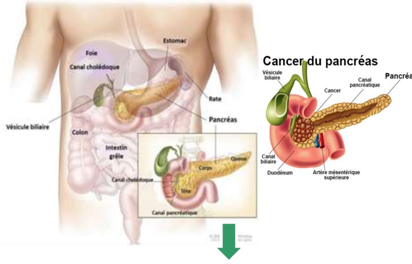
$$\mathbf{K_{uu}} = \int_{\Omega_k} \bar{\mathbf{B}}_0^T \bar{\mathbb{C}} \bar{\mathbf{B}}_0 d\Omega + \int_{\Omega_k} \bar{\mathcal{B}}^T \bar{\bar{\mathbf{S}}} \bar{\mathcal{B}} d\Omega$$

$$\mathbf{K}_{\phi\phi} = \int_{\Omega_k} \left[\frac{1}{2c_w} \overline{\mathbf{B}}_\phi^T G_c l_0 \overline{\mathbf{B}}_\phi + \overline{N}_\phi (2\psi_0 + \frac{1}{4c_w}\frac{G_c}{l_0}\frac{\partial^2 w(\phi)}{\partial\phi^2}) \overline{N}_\phi^T + \frac{\eta}{\Delta t}\overline{N}_\phi \overline{N}_\phi^T \right] d\Omega$$

$$\psi_0(\mathbf{F}) = \frac{\mu}{2}[tr[\mathbf{F}^T\mathbf{F}] - 3] + \frac{\mu}{\beta}[(J^{-\beta} - 1)]$$

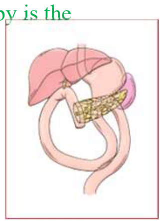
Context

- The pancreas is an organ of the digestive system, that ensures the regulation of glucose levels in the Blood.
- Pancreatic cells grow and multiply in an anarchic and uncontrolled manner introducing cancer forming a malignant tumor
- The constant increase in cases that have been identified for this cancer, and the study for the next few years lead to pancreatic cancer becoming the third cause of cancer death in the European Union and the USA.



Medical Solution: Surgery combined with chemotherapy is the main treatment for pancreatic cancer

The resistance to tearing of the tissues that make up the pancreas is a critical point in the reconstruction and recovery of the patient.



3. Phase-Field UEL/UMAT Algorithme

Initialize $u_0,\ \phi_0$

↓

Displacement step (n+1)

↓

Calculate $[K_{uu}]_i,\ [K_{\phi\phi}]_i,\ [R_u]_i,\ [R_\phi]_i,$ with $[u]_{i-1},\ [\phi]_{i-1}$

↓

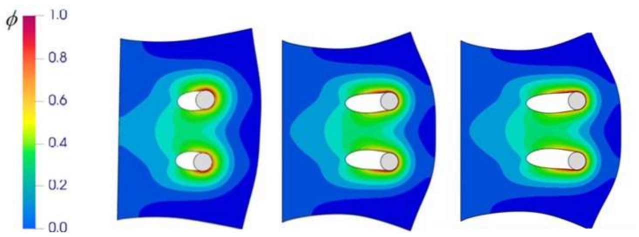
Solve $\begin{bmatrix} \mathbf{K_{uu}} & 0 \\ 0 & \mathbf{K}_{\phi\phi} \end{bmatrix} \begin{bmatrix} \Delta u \\ \Delta\phi \end{bmatrix} + \begin{bmatrix} \mathbf{R_u} \\ \mathbf{R}_\phi \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$ — Newton Raphson: Ith iteration

↓

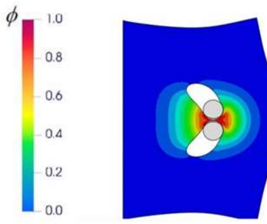
Update $[u]_i = [u]_{i-1} + \Delta u$ and $[\phi]_i = [\phi]_{i-1} + \Delta\phi$

Solution convergente: $[u]_{n+1} = [u]_n,\ [\phi]_{n+1} = [\phi]_n$

Results



Damage evolution patterns of the plate specimen at loading displacements Δu = 2.0 mm, Δu = 4.0 mm, Δu = 5.0 mm, respectively.



Damage evolution patterns of the plate specimen at oblic loading displacement Δu = 2.0mm, α=60°

Conclusion and perspectives

- Phase field method for modeling the fracture behavior of the hyperelastic materials subjected to large deformation proposed here in total Lagrangian formulation. The Neo-hooken model is used to describe the mechanical response of hyperelastic material.
- Propsition of combined of cohesive and phase-field model to solve distorsion mesh problem.

References

[1] D. Mumford, J. Shah, Optimal approximations by piecewise smooth functions and associated variational problems, Commun. Pure Appl. Math. 42 (5) (1989)577–685.

[2] Fucheng Tian a,b , Jun Zeng a,b , Xiaoliang Tang a,b , Tingyu Xu a,b , Liangbin Li a,b,c,2020. An adaptive edge-based smoothed finite element method (ES-FEM) for phase-field modeling of fractures at largedeformations

[3] Fucheng Tian a,b , Jun Zeng a,b , Xiaoliang Tang a,b , Tingyu Xu a,b , Liangbin Li a,b,c,2020. A dynamic phase field modelwith no attenuation of wave speed for rapid fracture instability in hyperelastic materials,