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LOCAL TOUGHNESS IN HUMAN CORTICAL BONE MICROSTRUCTURES BY AN X-FEM IMAGING TECHNIQUE

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ABSTRACT

We propose a procedure to investigate local stress intensity factors at the scale of the osteons in human Haversian cortical bone. The method combines a specific experimental setting [1] for three point bending milimetric specimen and a numerical method using the eXtended Finite Element Method (X-FEM) [2,3]. The interface between the experimental setting and the numerical method is ensured through an imaging technique that analyses the light microscopy observations to import the geometrical heterogenity of the Haversian microstructures and boundary conditions into the numerical model. The local mechanical elastic moduli are measured by nanoindentation and an imaging technique of the stress-strain fields. The model is able to access three scales of measures: the macro scale of the material level (mm), the micro scale inside the Haversian material for stress-strain fields (10-100 μm) in Figure 1, the sub-micro scale for the crack opening profiles (1-10 μm) in Figure 2 and fracture parameters (stress intensity factors) in Figure 3. The model is applied to several patients at different aging stages and compared to literature values at the micro scale [4].

REFERENCES

[1] T. Hoc, L. Henry, M. Verdier, D. Aubry, L. Sedel and A. Meunier, "Effect of microstructure on the mechanical properties of Haversian cortical bone", *Bone*, vol. **38**, 466–474, 2006.

[2] E Budyn and G Zi and N Moës and T Belytschko, "A method for multiple crack growth in britle materials without remeshing", *International Journal for Numerical Methods in Engineering*, Vol. **61**, 1741–1770, 2004.

[3] E. Budyn and T. Hoc,"Multiple scale modeling of cortical bone fracture in tension using X-FEM", *Revue Europenne de Mcanique Numrique (European Journal of Computational Mechanics)*, Vol. **16**, 213–236, 2007.

[4] D. R. Shelton, R. B. Martin, S. M. Stover and J C Gibeling, "Transverse fatigue crack propagation behavior in equine cortical bone", *Journal of Materials Science*, Vol. **38**, 3501–3508, 2003.

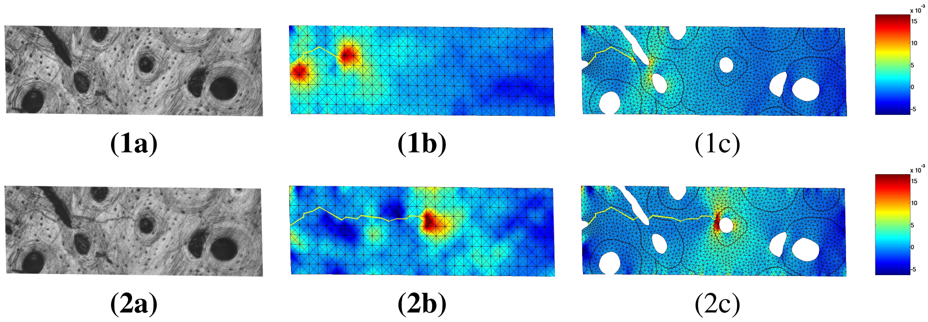

Figure 1: 1,2 (a) light microscopy observations of w06003 Haversian cortical bone samples under loading, 1,2 (b) ϵ_{22} strain field obtained by the X-FEM-imaging model where the displacement field is prescribed at each mesh point from CorrelmanuV data, 1,2 (c) ϵ_{22} strain field obtained by our X-FEM model that reconstruct the explicit microstructure where the experimental displacement field is prescribed along the edges.

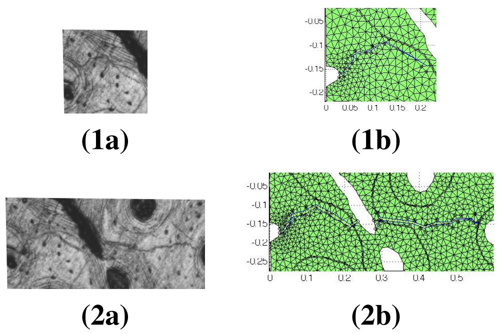

Figure 2: 1,2 (a) light microscopy observations of w03006 Haversian cortical bone samples under loading, 1,2 (b) ϵ_{22} strain field obtained by the X-FEM-imaging model where the displacement field is prescribed at each mesh point from CorrelmanuV data, 1,2 (c) ϵ_{22} strain field obtained by our X-FEM model that reconstruct the explicit microstructure where the experimental displacement field is prescribed along the edges.

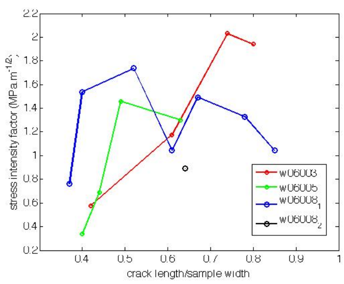

Figure 3: Local stress intensity factors in three cortical Haversian bone microstructure