Experimental and Numerical Analyses of Trabecular Bone Fracture

A Braesch-Andersen*, J Carlsson, C Öhman Mägi, C Persson, S J Ferguson†, P Isaksson

Department of Engineering
Uppsala University
Uppsala, Sweden
e-mail: anna.braech-andersen@angstrom.uu.se

† Institute for Biomechanics
ETH Zürich
Zürich, Switzerland

ABSTRACT

The majority of bone fractures are results from impulse loads [1]. Impulse fractures in low-quality porous (osteoporotic) bone are a major cause of long-term pain and physical disability, and have an enormous impact on the health care social systems [2]. However, the understanding of the fundamental aspects in rapid bone fractures is still in its infancy [3], mainly because such fractures depend on complicated interplays between load impulses, stress waves and mechanical properties on the tissue level.

High-resolution three-dimensional phase field finite element models are in this project used to analyze fundamental phenomena involved in deformation and fracture of trabecular bone. Bone specimens subject to both quasi-static load and impulse-load are studied. Additionally, opening mode fracture experiments were conducted in-situ using synchrotron X-ray computed tomography (TOMCAT, PSI, Switzerland) via step-wise loading/scanning of human trabecular bones in which microscopic cracks nucleated, propagated stable, and eventually coalesced to form final global fractures. The numerical models are discretized using three-dimensional high-resolution images obtained in scans of unloaded bone samples. The quasi-statically loaded numerical models perfectly reproduce the experimentally observed stable crack growth and crack paths and, hence, lend confidence to the phase field fracture models [4]. However, the impulse-loaded numerical models produce quite different fracture behavior compared to the quasi-static models: cracks are nucleated at different positions and grow unstable along altered paths [5]. The diverse crack behavior in the two loading situations -static and dynamic- thus clearly reveal the different fracture mechanisms involved and indicate that dynamical properties have to be taken into consideration when e.g. improving fracture treatments of low-quality bones.

REFERENCES

[1] J Parkkari, P Kannus, M Palvanen, A Natri, J Vainio, H Aho, I Vuori, M Järvinen. Majority of hip fractures occur as a result of a fall and impact on the greater trochanter of the femur: a prospective controlled hip fracture study with 206 consecutive patients. Calcified Tissue Int 65:183-187, 1999

[2] R Norris, D Bhattacharjee, MJ Parker. Occurrence of secondary fracture around intramedullary nails used for trochanteric hip fractures: a systematic review of 13.568 patients. Injury 43:706-11, 2012

[3] P Fratzl. Bone fracture: When the cracks begin to show. Nature Materials 7:610-612, 2008

[4] J Carlsson, P Isaksson. Dynamic crack propagation in wood fibre composites studied by high speed photography and a dynamic phase field model. Int J Solids Struct 144:78-85, 2018

[5] J Carlsson, P Isaksson. Crack dynamics and crack tip shielding in a material containing pores analysed by a phase field method. Engng Frac Mech 206:526-540, 2019