

# THE EFFECT OF BONE MICROSTRUCTURE ON MICROCRACKS PROPAGATION TRAJECTORY

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## INTRODUCTION

Haversian cortical bone is a biological fiber – ceramic matrix composite material (Yang et al. 2006) with varying microstructural arrangements at different scales that provides sites for microcracking. In this composite material, osteons are considered as fibers and interstitial tissue as a matrix (Raeisi Najafi et al. 2007a). The interface between the osteons and interstitial tissue is also presented by cement line.

Fracture phenomena in the Haversian cortical bone are primarily affected by the morphology and heterogeneity of the microstructure (Huang et al. 2006; Raeisi Najafi et al. 2007b). Any variations in these parameters caused by the aging process, on the other hand, make the problem rather more complicated. As an example, the aging process increases the differences in the mechanical properties of osteons and interstitial tissue. This has a profound effect upon the fracture behavior of bone. It was thus necessary to enhance the understanding of the mechanisms governing fracture in Haversian cortical bone.

To this effect, the focus of this paper is to evaluate the microstructural effect of osteonal cortical bone upon the fracture phenomenon. The approach is to provide a suitable fracture model of the microstructure using finite element method (FEM) and then to evaluate the modeling outcomes by studying the SEM micrographs of a fracture test.

## METHODS

### *Finite element model*

In this study, the osteons are considered as fibers since they are approximately circular in shape and orientated parallel to the longitudinal axis of the bone. Furthermore, the interstitial tissue which fills the space between the osteons is considered as a matrix. The cement line or the interface between the osteon and the interstitial tissues is also included in the model.

Mechanical properties of bone constituents could be severely affected by factors such as bone type, anatomical location, age, gender and others. To this effect, values of 15-25 GPa for osteonal effective elastic modulus ( $E_o$ ) and 20-27 GPa for interstitial tissue elastic modulus ( $E_i$ ) are thus adopted for the evaluation of the effect of mechanical properties upon microcrack behavior. Here, Poisson's ratio for the osteon and the interstitial bone is assumed to be 0.3.

The mechanical characteristics of the cement line tissue have also been the subject of different studies. A series of reports consider this tissue softer than its surrounding tissues (Hogan, 1992). Other researchers such as Curry (1984) suggest a more mineralized structure and thus a higher modulus of elasticity (Hogan, 1992). In this paper, following the suggestion made by Advani et al (1987), the simulation is repeated twice for values of 10 and 30 GPa with the assumed Poisson's ratio of 0.4 (Hogan, 1992).

The computer program Casca Version 1.4 is used to produce a two-dimensional mesh. Fracture analysis is performed using Franc2D which is a Finite Element Modeling tool. The model is then used to analyze fracture propagation.

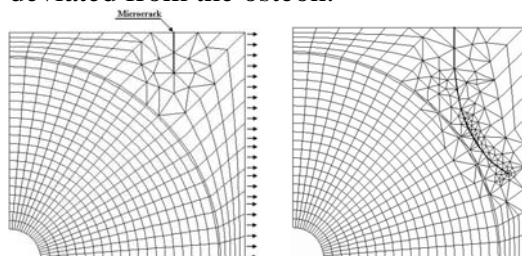
#### *Experimental test*

Compact bone samples are removed from bovine femur within 24 hours of slaughter. Distal and proximal ends are removed and the remaining section is divided into six approximately 5 cm long portions. The portions are cleaned from any soft tissues, preparing the way to obtain 23 standard (ASTM-E399) CT samples. Samples are mounted on a dynamic testing machine (Zwik/Roell 321 htm 123) using specially prepared fixtures. Slow fracture condition occurs during tension loading at a crosshead rate of 0.005 mm/sec. Fractured samples are gold coated at the pressure of 0.001 mbar and the SEM produces photographs of the fracture surfaces.

## RESULTS AND DISCUSSION

#### *Finite element model*

In the first case, the edge microcrack is situated in a vertical direction to the loading (Figure 1). It is shown that within the adopted range of elastic moduli for different tissues, the microcrack trajectories are deviated from the osteon.



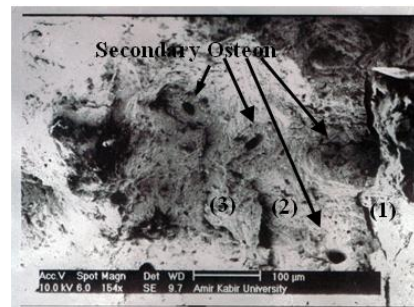
**Figure 1:** Microcrack propagation trajectory under tension.

#### *Fracture test*

A fracture surface is shown in Figure 2. The precrack orientation is perpendicular to

longitudinal bone axis. The microcrack deviation from the osteon or its halt, once approaching the cement line boundary is evident in this picture.

Microcrack propagation trajectory is influenced by the Haversian cortical bone microstructure. The Scanning Electron Microscope photographs of fracture surfaces and the results of finite element modeling seem to be supporting one another. Results indicate that some of the microcracks are deviated as they approach the osteons. This deviation is dependant upon such parameters as osteon density. When the distance between osteons is small and the osteon density is higher, then microcrack propagation can not follow a trajectory between the osteons and stops at the cement line boundary. It could therefore be concluded that osteons act as a barrier against microcrack propagation.



**Figure 3:** SEM fracture surface picture of a bovine femur sample.

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