Stress Cracking Behavior of Interstitial Matrix and Cement Line Interface Deflection

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Abstract

Bone can be noticed as a complex hierarchically organized structures at all length scales, which has both metabolic and mechanical functions. One of the major type of bone is known as cortical bone as it comprises of distinct microstructures including osteons, interstitial bone, and cement line which play an important role in examining the fracture behavior in cortical bone. Microcracking of these unique features may lead to bone fracture. To date, there are a few of studies have been done regarding to its special microstructures. However, the mechanical properties of cement line is absent described to predict the cracking behavior at micro-scale level. This study aims to determine the stress distribution of cement line deflection in single osteon using finite element (FE) method. A FE analysis were performed to simulate the secondary osteon model under mode I, mode II and mixed-mode loading. The finding of this study propose the stress is accumulated near to the cement line. The maximum stress may be found to be high at the longest crack. The study concluded that the stress cracking behavior of cement line deflection is influenced by different mode of loading.

Keywords: Cortical bone; Cement line deflection; Finite element analysis; Maximum stress; Mode of loading.

1. Introduction

Bone is known as a unique hierarchical composite material that can be considered at multi-length-scale from nanometer scale to the macroscopic level. Some factor of ageing and disease can altered the mechanical properties of bone which increasing the tendency of bone to be fractured [1]. Figure 1 shows schematic diagram of cortical bone microstructures. At the microscopic level, the microstructures of cortical bone are comprises of osteons, which consist of Haversian canal that surrounded by lamellae and cement line that bounded the osteons. Besides, the bone strength and fracture behavior are provided by these distinct microstructure, and not been completely understood [2].

Fig. 1: Schematic diagram of cortical bone microstructures. Adopted from [3].

Basically, there is a stage in which microcracking occurs, before the bone fractures as an outcome of imposed strains being more than it can bear [4]. The several factors such as bone loss, heterogeneous microstructure, variation of its material properties and accumulation of microcracks were influenced a fracture process in a cortical bone tissue [5]. Thus, the fracture processes need to be understand in order to develop strategies for the prevention and treatment. The previous study on the crack propagation and microstructure of the cortical bone, which mainly cement line displayed that the microcracks were arrested at the cement line [6]. This finding showed that the cement line was plays a role to inhibit the propagation of microcracks. Nevertheless, the mechanical behavior of the microcracks arrested at the cement line is not well discussed. Thus, further efforts are required to simulate how the cement line involved in inhibiting the microcracks at the microscale level. The crack deflection plays a main role, which mostly increase bone toughness by increasing the work of fracture [7]. The crack path was changed by altering the crack angle from the minimum energetic configuration. This is due to the osteon and cement line mechanism which acts as barriers along with their size and density [8]. The study on the mechanism of crack propagation in the single osteon and the role of cortical bone microstructure revealed that the crack growth was prevented or slowed down due to the obvious effect of cement line that acts as a barrier [9]. This past study also suggested that the future investigations can be performed in details to examine the phenomenon of crack deviation by adding more the effect of osteons.