INTRODUCTION

The reasons behind the arrestment of microcracks in cortical bone are not completely understood. Two phases are assumed for the process of arresting a crack initiated in interstitial bone. In the first phase, the instability of the crack is increased, the crack propagation direction is changed, and the crack is attracted toward soft osteons.\(^1\) In the second phase, once the crack reaches the osteon site, it is arrested at the cement line or somewhere inside the osteon. Experimental results and numerical analyses have both verified the phase one assumption.\(^1\) In this work, we investigated how osteons can arrest cracks, as observed by us and others (Figure 1). We studied the influence of cement line thickness and modulus and intra osteon modulus on the stability of crack propagation.

Figure 1. Typical microcracks (arrows) in cortical bone sections. Crack arrested at cement lines at both ends (left). One end of crack arrested at cement line and other end arrested within osteon (right).

TISSUE MICROSTRUCTURE OF OSTEONAL BONE

Osteonal bone consists of stiffer interstitial bone and softer osteons.\(^2\) A typical osteon consists of a Haversian canal, intra osteon lamellae, and a cement line (Figure 1). The cement line is assumed to be the softest of these constituents.\(^3\) The approximate diameter of an osteon is 200 µm. The cement line is 1 to 5 µm in width.

CRACK PROPAGATION IN OSTEONAL BONE

Herein we only consider crack propagation in planes perpendicular to the osteon’s axis. All materials in the crack propagation plane are treated as isotropic. A square one-osteon model (Figure 3) is used to study the characteristics of crack propagation within an osteon. All cracks are assumed to be either in the cement line or the intra osteon lamellae area. Four possible initial horizontal cracks with length 2\(l\) at points a, b, m, n are considered. For each case only one of the four cracks exists.

The ratio of the side length (\(L\)) of the square plate to the external diameter (\(D\)) of the osteon is set to 10. The ratio of \(D\) to Haversian canal size \(d\) is set to 4, the ratio of all crack lengths 2\(l\) to \(D\) is set to 0.03, and the ratio of applied displacement \(\delta\) to \(L\) is set to 0.01.

Let \(E_0\), \(E_c\), and \(E_i\) be Young’s moduli of the three materials in the interstitial, cement line, and intra osteon areas, respectively. For the four possible cracks, we introduce the following normalized mode I stress intensity factors

\[
a_{I1,j} = \frac{K_{I1,\text{left}}^{(a)}}{(E_0\delta\sqrt{\pi l})/L}
\]

\[
a_{I2,j} = \frac{K_{I1,\text{right}}^{(a)}}{(E_0\delta\sqrt{\pi l})/L}
\]
