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Research paper

Effects of age and loading rate on equine cortical bone failure

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ABSTRACT

Although clinical bone fractures occur predominately under impact loading (as occurs during sporting accidents, falls, high-speed impacts or other catastrophic events), experimentally validated studies on the dynamic fracture behavior of bone, at the loading rates associated with such events, remain limited. In this study, a series of tests were performed on femoral specimens obtained post-mortem from equine donors ranging in age from 6 months to 28 years. Fracture toughness and compressive tests were performed under both quasi-static and dynamic loading conditions in order to determine the effects of loading rate and age on the mechanical behavior of the cortical bone. Fracture toughness experiments were performed using a four-point bending geometry on single and double-notch specimens in order to measure fracture toughness, as well as observe differences in crack initiation between dynamic and quasi-static experiments. Compressive properties were measured on bone loaded parallel and transverse to the osteonal growth direction. Fracture propagation was then analyzed using scanning electron and scanning confocal microscopy to observe the effects of microstructural toughening mechanisms at different strain rates. Specimens from each horse were also analyzed for dry, wet and mineral densities, as well as weight percent mineral, in order to investigate possible influences of composition on mechanical behavior. Results indicate that bone has a higher compressive strength, but lower fracture toughness when tested dynamically as compared to quasi-static experiments. Fracture toughness also tends to decrease with age when measured quasi-statically, but shows little change with age under dynamic loading conditions, where brittle “cleavage-like” fracture behavior dominates.

1. Introduction

Bone is a complex hierarchical material with a highly anisotropic structure and mechanical response that varies depending on loading rate and orientation (Saha, 1982). Beginning at the nano-scale regime, the main constituents of collagen and calcium phosphate mineral are assembled in successively larger structures forming a material that adapts to support bodily loads, allows ingrowth of tendons and ligaments, resists fracture, and even self heals (Martin et al., 1998; Rho et al., 1998; Ritchie et al., 2006). However, its complex architecture and ability to adapt locally and globally to external loads (Les et al., 1997, 1998) has led to a poor understanding of how bone’s hierarchical structure interacts

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