FATIGUE LIFE PREDICTION IN A CANCELLOUS BONE STRUCTURE

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ABSTRACT

Repetitive cyclic loading of bone during daily course activities is one of the primary causes of bone fracture in humans. Stress fractures and fragility fractures in elderly generation due to osteoporosis have been associated with the reduction of bone strength of the cancellous bone. The aim of this study is to predict the failure of cancellous bone as a function of density and porosity. In this present study, two of cancellous specimens were extracted from bovine medial-condyle bone and were loaded in cyclic compression. Monotonic compressions were first tested to determine the boundary conditions prior to the fatigue testing. The loading transferred to the cancellous bone are chosen between 16%-55% of the ultimate stress. The result showed different hysteresis loop with large variation in strain between both medial-condyle of cancellous bone. They both adapt different physiological apparent load until failure. From the obtained result, we can conclude that the same anatomic site with different value of bone density and porosity imply a large effect of the fatigue behavior in related to modulus degradation and strain changes.

ABSTRAK

Tahap aplikasi kitaran beban yang berulang-ulang pada tulang ketika aktiviti harian adalah salah satu penyebab utama keretakan atau fraktur tulang manusia. Tekanan retakan dan kerapuhan tulang terhadap golongan warga emas di sebabkan oleh penyakit osteoporosis sering dikaitkan dengan pengurangan daya kekuatan pada tulang kanselus. Tujuan utama pengajian ini adalah untuk menjangka tahap kegagalan tulang kanselus sebagai fungsi kepada ketumpatan dan poros. Dalam ujikaji ini, dua sampel dari tulang tengah dari bovin telah diekstrak dan diuji pada tahap kitaran beban yang berulang-ulang. Bebanan termampat secara monotonic telah diuji terlebih dahulu untuk menentukan garisan panduan untuk uji kaji seterusnya, iaitu bebanan termampat yang terjurus kepada kegagalan terhadap sampel tulang kanselus. Aplikasi galas beban terhadap tulang kanselus telah ditentukan daripada 16% sehingga 55% daripada maksimum stres daripada bebanan termampat secara monotonic . Keputusan menunjukkan ketidaksamaan pada hysteresis loop dengan perubahan besar pada ketegangan di antara dua tulang tengah kanselus. Daya ketahanan pada kedua-dua tulang ini adalah berbeza sebelum fraktur. Daripada keputusan ini juga, kami mendapati walaupun lokasi anatomik yang sama tetapi berbeza dari segi ketumpatan dan poros, mempengaruhi besar terhadap tingkah laku daya ketahanan tulang kanselus tersebut. Ini adalah berkaitan dengan modulus dan ketengangan daripada ujikaji yang telah dijalankan.

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LIST OF ABBREVIATION AND SYMBOL

V_t	-	Volume geometric
V_b	-	Volume hydrated
$W_h: g$	-	Weight in air
$W_s: g$	-	Weight in submerged
ρ	-	Density
V_f	-	Volume fraction
D_{app}	-	Material Density
E	-	Modulus Young
σ	-	Normal stress
ε	-	Strain
N_f	-	Number of cycle to failure

CHAPTER 1

INTRODUCTION

More than 250,000 hip fractures were reported in 1996; approximately 10% are thought to be spontaneous fractures associated with cyclic loading during the daily activities. Military recruits, athletes and ballet dancers are among those affected [1]. Under physiologic conditions, micro-damage events created from both static and cyclic load are subsequently repaired through the coordinated process of bone remodeling [2]. Micro-damage accumulation leads to diminished bone quality and together with loss of bone quantity, results in weakened bones which may break following minor falls [3].

There are two types of bone tissue in the skeletal system; cortical (or compact) and cancellous (or trabecular) bone. Adult human skeletal mass consists of 80% cortical bone (porosity 5-30%) and 20% (porosity 20-90%) cancellous bone [4]. The micro-damage accumulation incidence is greatest at sites where cancellous bone is the dominant form and has increased over the past 30 years [3]. Thus, changes in cancellous bone stiffness in even a small region can cause large differences in whole bone strength [5]. Repetitive cyclic loading of bone during the daily course of activities is one of the primary causes of bone fractures in humans [6]. A typical loading for bone is cyclic loading that is variable in time; behaviors under such loading can termed ‘fatigue behaviors’ [7]. Excessive fatigue loading of bones in vivo can lead to micro crack accumulation and coalescence, reducing stiffness and strength and increasing the risk of fracture [8].

The fatigue behavior of cancellous bone has been characterized in a number of studies [1,6,8,13,39,40,42]. In these experiments, the fatigue life of these cancellous bones was observed and characterized by the number of cycles to failure, N_f, increases as the cyclic decreases. The mechanical response of the cancellous bone under fatigue was characterized by a decrease in the elastic modulus throughout the test, with rapid modulus loss near failure, and increasing plastic, or permanent strain [8, 9]. They also found increasing residual strain and modulus reduction with increasing strain amplitude [2].

A study showed that bone fatigue can occur at strain magnitudes comparable to those measured on living bones in the physiological loading environment during vigorous activity in animals and humans. From this study, the fatigue life to failure is predicted in the order of 10^7 load cycles, which is approximately 5-10 years of use in life [9]. Significance amounts of fatigue damage occur throughout the loading history; damage which must be repaired in order not to lead to fatigue failure of skeletal elements [9].

Fatigue fractures are usually sustained during continuous strenuous physical activity which causes the muscles to become fatigued and reduces their ability to contract. Fatigue fractures on the compressive side appear to be produced more slowly because the remodeling is less easily outpaced by the fatigue process, thus the bone may not proceed to complete fracture [10]. The ability of the skeleton to resist fracture under applied loading varies primarily through changes in these constituents of bone failure load and bone strength [11]. Most the site that is prone to fractures due to this disease is at the hip, vertebrae and the distal radius [12]. This is because of their high prevalence and their frequent asymptomatic characteristics which are associated with low bone mass and micro architectural deterioration [13].

If the applied load exceeds the failure load of the bone of interest, then the factor of risk is greater than one and fracture will occur. Thus, to predict fracture accurately, characteristics of the applied load such as the manner and location of its applications must be considered [11]. Fatigue behaviors on cancellous bone induced by many case of physiological human activities which can contribute to stress fracture from various activity such for athletes and fragility fracture in aging. Studies have shown that the volume fraction of cancellous bone strongly influences the mechanical properties specifically the compressive strength, stiffness and elastic modulus [14]. Hence, understanding the damage properties of cancellous bone is important to understand bone fractures [15]. Past study by Bowman et al. (1994) showed that modulus of the cancellous bone can decrease with fatigue as the strain accumulation increases due to creep [16].

In the course of everyday activities human bone is submitted to a great variety of loading patterns. The loading varies in direction, magnitude, frequency and mode (tension, compression and shear) and also in combinations of the previous factors [17]. This repetitive physiological loading pattern is referring to human gait cycle. This fundamental task has been the subject of study by scientists for several centuries, both with respect to description of typical body movements and of pathological conditions and therapeutic interventions [10].

1.1 Objective

The objectives of the research project are to:

1. To predict of fatigue life of cancellous bone structure.
2. To analyze the fatigue behavior of cancellous bone respect to physiological axis

3. To study relationship of morphological indies with fatigue life of cancellous bone structures.

1.2 Scope

The scope of this proposal will cover as below:

1. Cancellous bone sample preparation.
2. Morphological data of cancellous bone structure.
3. Experimental set up
4. Fatigue behavior analysis

1.3 Problem Statement

The rising incidence of osteoporosis within the aging society is becoming a major health problem. Aged-related osteoporosis is a systemic disease characterized by reduced bone mass and deteriorated bone micro-architecture which associated in decrease in strength and in Young's modulus as a result of significant disturbance in bone structure that includes a decrease in the number of cancellous and their thickness [7]. Elderly patients with osteoporosis are particularly prone to fragility fractures of the vertebrae, where load is carried primarily by cancellous bone [8]. As the aging and elderly population grows, so will the prevalence of osteoporosis and the cost of treatment.

Damage accumulation under compressive fatigue loading is believed to contribute significantly to non-traumatic, age-related fractures in femur bone. The advantage of using the compressive fatigue tests is the ability to conduct variable test with the use of small numbers of samples [7]. Even if these failure types are of known, data for cancellous bone exposed to cyclic loading are still insufficient [18]. Studies of the fatigue of bone have dealt most extensively with cortical bone since it is consequently plays a dominant role in determining the overall strength of a given bone of the skeleton [10].

A great number of investigations have probed the mechanical properties of both cortical and cancellous bone. Studies have investigated the Young's modulus, yield strain, creep behavior and fatigue behavior of both cancellous and cortical bone [19]. The proximal femoral head exhibited of hip contact forces [20] has been studied for average patient. This has been developed the maximum peak forces during human activities and it has contributed such a loading method to be apply on fatigue analysis in cancellous bone. In revision of total knee arthoplasty, the epicondyles often provide the only available clues for rotational and proximal/distal positioning of the femoral component. Thus, a relevant study of the anatomic relationship based on the epicondyles of the distal femur will somehow help orthopedists position the femoral components appropriately in primary and revision total knee arthoplasty [21]. It is also significance for this study in order to obtain the main physiological axis for the load to transmit to the epicondyle femur.

From previous study, it is suggested that more than 75% of the load adjacent to endplates is carried by cancellous bone [22]. The relationship between morphology of cancellous bone to the mechanical properties and failure mechanism can be accessed through experimental and computational means [23]. Computer simulation (microCT) has become more accessible in the past years [13], but these data are still connected to many problems such as the high costs of the microCT scans and the rare availability of the high end scanning facilities.

The underlying deformation and damage mechanism within cancellous bone with respect to physiological activities are not yet sufficiently investigated. Thus, it is necessary to evaluate bone quality parameters such as the morphological index of the cancellous bone structure. In order to obtain the loading conditions, the monotonic test were first tested and performed into the fatigue testing. This paper will determine the prediction of the compressive fatigue behavior on several sample of cancellous bone as a function of density and porosity.

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