

Effect of Age on the Elastic Modulus of Bone

Waseem Ur R*

Department of Mechanical Engineering, International Islamic University, Islamabad, Pakistan

Abstract

The deterioration of the mechanical properties with aging is the major cause of the fracture of bone in the elder population. The elastic modulus (Young's Modulus) deteriorates in aging bones. An understanding is essential to know how elastic modulus degrades in aging bones. In the present study, tensile testing experiments on the bovine hip joint bone have been performed in both longitudinal and transverse directions to investigate the effect of age on the elastic modulus of bovine hip joint bone. The samples for testing are taken from the age groups 1-5 years. From these experiments, the elastic modulus is determined both in longitudinal and transverse directions. It is found that the elastic modulus deteriorates both in longitudinal and transverse directions with increasing age. It is investigated that the deteriorated modulus is higher in the transverse direction as compared to the longitudinal direction.

Keywords: Hip bone; Elastic modulus; Age effect; Tensile testing; Universal testing machine

Introduction

Bone is a natural composite anisotropic material, mainly composed of three materials: organic, inorganic, and water [1]. The bone primarily contains approximately 70% mineral, mainly hydroxyapatite (HA), and 8% water by weight, 22% proteins (90% type I collagen) [2,3]. Bone performs multiple functions in vertebrates, including structural support to organisms, protection of internal organs [4,5], and transmission of forces.

The hip bone is the major bone that constitutes the pelvis. Embryologically, it is made up of three bones: ilium (the winged or expanded upper portion), ischium (the lowermost portion), and pubis (the front or interior portion) as shown in Figure 1. After puberty, all these three bones start fusing, forming the hip bone. The hip bone articulates with the sacrum through the sacroiliac joint, in between of two hip bones below both sides. The joint of the femur and hip bone is a ball-and-socket joint in which the femur head serves as a ball and the hip bone acetabulum serves as a socket. While the sacroiliac joint is a fibrous joint which allows limited movement and is supported by a lot of strong ligaments [6,7].

The mechanical properties of the bone consistently change with increasing age. In this research paper, elastic modulus has been used in order to find and investigate the changes in the mechanical properties of the bone. Literature review shows that elastic modulus and mechanical properties of cortical and femoral bones change with increasing age. Leng et al. investigated the response of mechanical properties by considering the age effect of human cortical bone and for collagen phase in different orientations [8]. Micro tensile tests were performed on young, middle, and elderly age human bone donor's demineralized cortical bone, and aging effects for the different orientations for the mechanical properties of the collagen.

The analysis indicated that the ultimate strength and elastic modulus of the demineralized bone specimens decreased with aging in both the transverse and longitudinal orientations, and there is no change in failure strain in both directions irrespective of aging. Results suggested that collagen strength and stiffness of bone deteriorated with aging for both directions as shown in Table 1. The failure strain of the collagen phase in both orientations irrespective of aging is not observed, and it is concluded that the failure of the collagen phase does not depend upon aging and orientation.

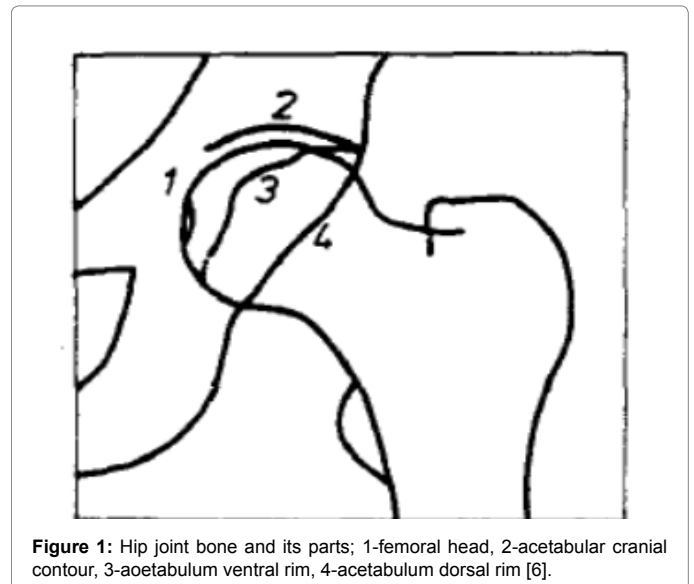


Figure 1: Hip joint bone and its parts; 1-femoral head, 2-acetabular cranial contour, 3-acetabulum ventral rim, 4-acetabulum dorsal rim [6].

Zherrina et al. performed compression and optical microscopy tests in the transverse and longitudinal directions for the protein portion of bone and mineral portion of bone to investigate the mechanical properties of bovine femur bone of different ages [9]. The optical microscopy test shows that the microstructure of young and mature bone, the results show that the mature bone is less porous and more stable than the young bone, and found that mature bone is stronger and less tough in both directions, longitudinal and transverse, for the case of mineral part of bone and protein part of bone. For the protein part of the mature bone, the strength is less than that of young bone. The elasticity of bone is 68% increase.

*Corresponding author: Waseem Ur R, Masters Degree Program in Department of Mechanical Engineering, International Islamic University, Islamabad, Pakistan, Tel: 03418852515; E-mail: enr.waseem778@gmail.com

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Age group	Ultimate stress Transverse (MPa)	Ultimate Stress Longitudinal (MPa)
Young Age	4.48	19.9
Middle Age	2.91	15.4
Elder Age	2.31	13.2

Table 1: Mechanical properties of collagen fiber with age [8].

from young age to mature age.

Similarly the Zioupos and Currey carried out the research on the variation in the elastic modulus, stiffness, strength and toughness of human cortical bone in aging bone [1,3,10-12] for the human male age group from 35-92 years, From their experimental investigation they observed that the elastic modulus, stiffness, strength and toughness decreases with increasing age in aging bones (Figure 2).

Materials and Methods

Materials and specimen preparation

For material and preparation the fresh bones of hip joint were taken within 24 hours from male bovine of different age groups (1-6 years). The bones were kept in freezer at 0°C temperature. Within 48 hours the bones were passed from macining process. The hacksaw was used to cut the required bone samples. These bone samples were shaped using a file. Finally the 12 samples were shaped and prepared for tensile testing according to ASTM-D3039 standards [13]. Test Matrix of the specimen is given in Table 2. The locations are shown in the figure from where the samples were cut and prepared. The samples were prepapred in two categories one in longitudinal direction and the other in transvers direction because of the collagen orientation in bone. Two types of tensile test specimens were prepared, longitudinal and transverse. The tensile test specimen is geometry in shown in Figures 3 and 4.

Test procedure

The test was conducted in universal testing machine (UTM) WDW-E-100 at HITECH University Taxila. WDW-E Series is a new kind of electronic PC control UTM. The loading capacity of this UTM is 1000 KN. We measure and plot the loading force, deformation and crosshead stroke etc. The displacement range of the machine was ± 80 mm. The specimen was bolted in the steel fixture and held in the machine grips. The test setup is illustrated in Figures 5 and 6. The test was performed at normal room temperature and pressure conditions. The load applied by machine at a crosshead speed of 1 mm/minute. During the test, the computer connected to the machine recorded the applied load and corresponding deformation. The Computer records the applied load and corresponding deformation. The test was stopped as the specimen failed.

Tensile test data analysis

The stress σ was calculated using the equation

$$\sigma = F/A \quad (1)$$

In the above equation, F is the load applied and A is the cross sectional area of the specimen.

The strain ϵ in the specimen was calculated using the equation:

$$\epsilon = \delta/l \quad (2)$$

Where δ is the total deformation of the specimen until failure and l is the initial length of the specimen.

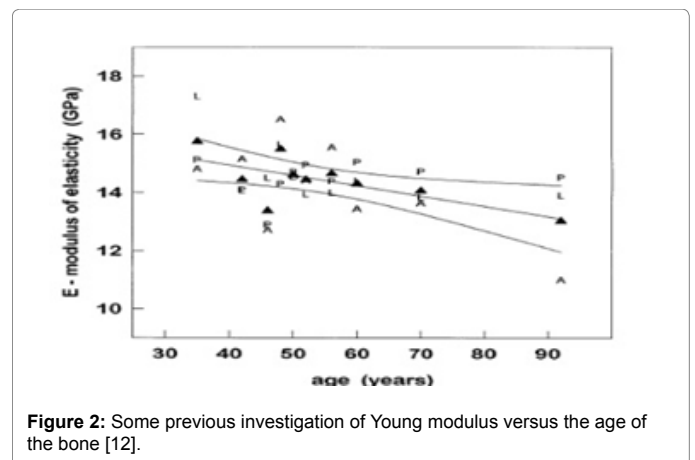


Figure 2: Some previous investigation of Young modulus versus the age of the bone [12].

The young modulus E was calculated by the following equation.

$$E = \sigma_{\max} / \epsilon_{\max} \quad (3)$$

Where σ_{\max} and ϵ_{\max} are the maximum stress and maximum strain at failure.

Results and Discussion

The modulus is lower at the young age of one year, up to three years for both longitudinal and tensile specimens respectively. The modulus after three years decreases gradually. This trend is very rare in the bone and it matches the result of the experimental data of the other species bones like human, bovine for young modulus calculation.

The research done on the variation in the stiffness, strength, and toughness of human cortical bone with Age by Zioupos and Currey, [1,3,12-14] observed in Figure 7 that the age significantly affects the young modulus and ultimate strength of human bone. They determined the fracture toughness, young modulus, and work fracture of human male aged bones between 35-92 years by doing experiments. They found that the all these mechanical properties decreases with age.

Conclusion

In this research experimental investigation of the age effect on elastic modulus of bovine's hip bone specimens was carried on. Young modulus was tested using flat specimens using ASTM D-3039 in universal testing machine.

These results show that changes in the young modulus with increasing age are higher for transverse specimens. The higher values are attributed to the presence of resisting collagen fibers. The variations in the values of the above properties with respect to age were more sensitive in the case of bovine bones as compared to the human bone behavior. This is due to shorter life span of the bovines than human. On the other hand; the properties of hip bones are similar to the cortical bone properties.

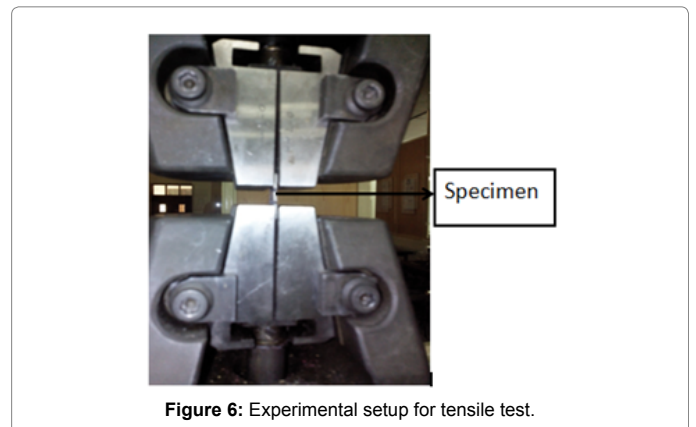
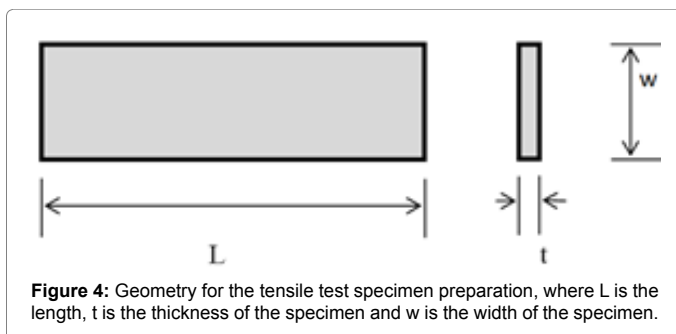
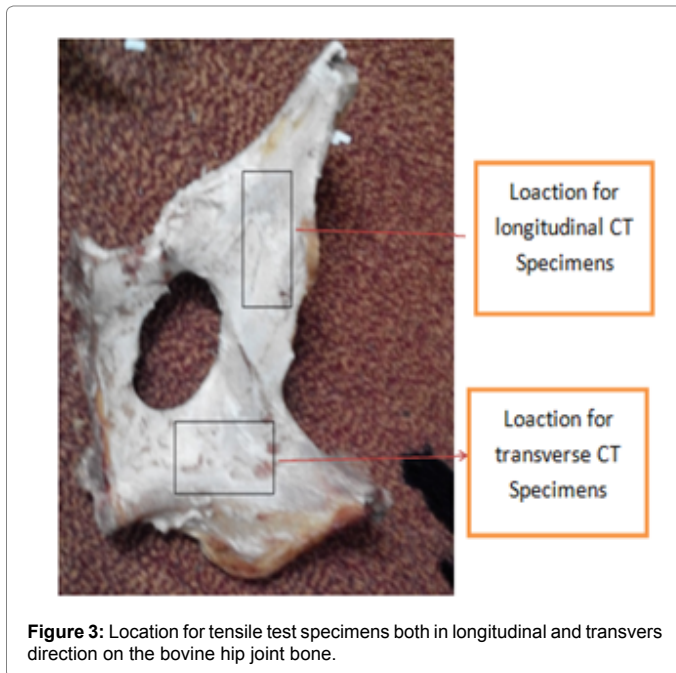
We concluded from our research data the elastic modulus of the hip joint bone decreases in aging bones both for the longitudinal and transver hip bone specimens. The previous research on the variation in the stiffness, strength, and toughness of human cortical bone with Age by Zioupos and Currey, [1,3,12-14] showed that the young modulus and ultimate strength of human bone decreases with increasing age.

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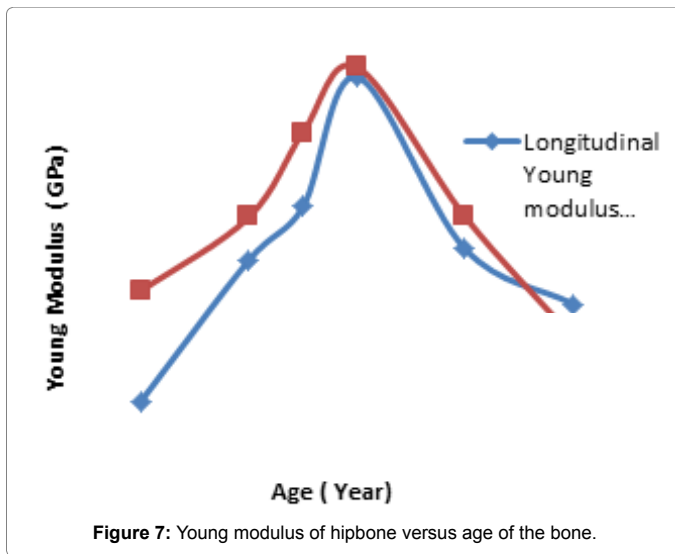
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S.No	Specimen Name	Age	Longitudinal Tensile Test Specimen	Transverse Tensile Test Specimen	Width (mm)	Length (mm)	Thickness (mm)
1	S1	1	✓		16.54	7.4	2.1
2	S1	1		✓	16.22	5.91	2.18
3	S2	2	✓		16.46	6.21	2.7
4	S2	2		✓	16.28	5.7	3
5	S3	2.5	✓		13.26	4.07	1.91
6	S3	2.5		✓	17.68	6.35	2
7	S4	3	✓		15.88	3.91	2.3
8	S4	3		✓	12.32	3.3	2.03
9	S5	4	✓		16.22	5.7	2.36
10	S5	4		✓	16.22	5.08	2.5
11	S6	5	✓		13.3	5.08	1.91
12	S6	5		✓	16.26	5.15	2

Table 2: Test matrix of CT specimens.



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