ID: 2016-ISFT-136

Study of Impact Strength of Biomaterials (Bones)

Rajiv Chaudhary[1], Ramesh Chandra Singh[2], Ranganath M. Singari[3]

[1,2,3]*Dept. of Mechanical Engineering, Delhi Technological University, Delhi*
[1]*rch_dce@rediffmail.com*

Abstract: *Major structural support to the human body is provided by the skeleton, which comprises several joins through which bones are connected, with each other, forming a structure. Apart from performing various roles of kinematics, posture, muscular contraction control, and internal organs protection, Skeleton also withstands various types of loadings applied to the body in various physical activities. Subsequently, it becomes important to study the mechanical behavior of the bone, through its various mechanical properties like Strength, Toughness, Fatigue strength and Hardness etc, which have been matter of interest in this context. Out of various types of loadings, the suddenly applied load has been more critical to the skeleton as well as bones, as through suddenly applied load or impact considerably more stress is developed in comparison to other loading conditions. Also, the explanation of this mechanical property from the fracture mechanics concept looks to be very prospective, with more and more new possibilities. Although the basic methods of assessing this property is based on load-bearing capacity in form of stress, as done with other engineering materials. But biomaterials like bone, being a living material, happens to be very different which are capable of self-repair and adaptation. Obviously, the Quantitative measurement of toughness of bone would become an integral part of the mechanical assessment of this biomaterial and in evaluating this, we also need to address some other issues like age, activity, deficiencies, disease and therapeutic treatment etc. In this context, the considerations have been made about the issues related to various physical activities, sports, exercises, as well as injuries/fracture and its effect over toughness of bone have been studied. Different studies have been made by the researchers focusing on various aspects of this mechanical property of toughness, with respect to principle, theory, methodology as well as various experimental evaluations done with this biomaterial. In this paper an attempt has been made to make a comparative study of various aspects of evaluating toughness of bone and to assess structural issues etc of the bone in this context.*

Keywords: *Multiple intelligence theory*

1. INTRODUCTION

The skeleton consisting of multiple type of bone has to perform multiple roles in human body. Along with providing shape and the structural support to the body it performs several important functions like providing basis to the posture, in opposing muscular contraction conveying locomotion, in sustaining the daily challenges of different types of load and ultimately in protecting the internal organs of the body.

Many of these studies carried out mechanical testing in order to evaluate how the structural properties of the bone are affected. Out of these, the basic structural properties of greatest importance have been found to be generally the stiffness, strength and toughness. Under the circumstances procedure has been established to assess the mechanical properties of biomaterials too. A comparison of the mechanical properties of biomaterials with other engineering materials can be seen in Table 1 [1].

TABLE 1. Mechanical Properties of Metallic and Bio Materials [1]

Material	Young's Modulus, E (GPa)	Yield Strength, s_y (MPa)	Tensile Strength, s_{UTS} (MPa)	Fatigue Limit, s_{end} (MPa)
Stainless steel	190	221–1,213	586–1,351	241–820
Co-Cr alloys	210–253	448–1,606	655–1,896	207–950
Titanium (Ti)	110	485	760	300
Ti-6Al-4V	116	896–1,034	965–1,103	620
Cortical bone	15–30	30–70	70–150	

In case of non living engineering materials, the standardization in measuring material properties is possible, but with biomaterials it is difficult to conduct valid measurements of such properties. In case of bones it may be due to the size limitations of the samples that can be fabricated due to physiological reasons or because of difficulties associated with small sample sizes available in some bones, (this is even more difficult for some orientations). From several studies it has been found that on the structure and properties of bone there are many factors like the age of the person, existing disease if there is any as well as drug administered, apart from it depending on material only [6–14].

ISBN: 978-93-84935-64-1

2. TOUGHNESS OF A BIO MATERIAL

Out of various types of functions, it is also worthy to analyze the functions of the bones from biomechanical point of view. From this point of view we need to study the likely effects and damages caused by the external injuries and trauma. In most of the situations the stress caused is by Impact, which generates stresses of greater magnitude in comparison to other type of loading conditions. Under these circumstances the study of toughness as mechanical property becomes important, as the toughness of a material gives measurement of resistance to fracture under impact loading conditions. In this paper a study has been made of various aspects of Toughness or Impact strength with respect to Bone.

In general the measurement of Toughness may be taken graphically from the stress–strain curve, which shows how a material of a given area deforms for a given load. The area under the curve represents the amount of work done, or energy stored per unit volume, by the material at any given point on the curve. More the area under the curve, more is the Toughness as it shows that the tough material can absorb a greater level of load before fracture or failure. At the point of ultimate failure, the whole area under the curve defines the energy required for breaking the object, or toughness. On the basis of this measurement a comparison may be assessed between the Mechanical properties of Strength, Toughness and Ductility in Fig 1.

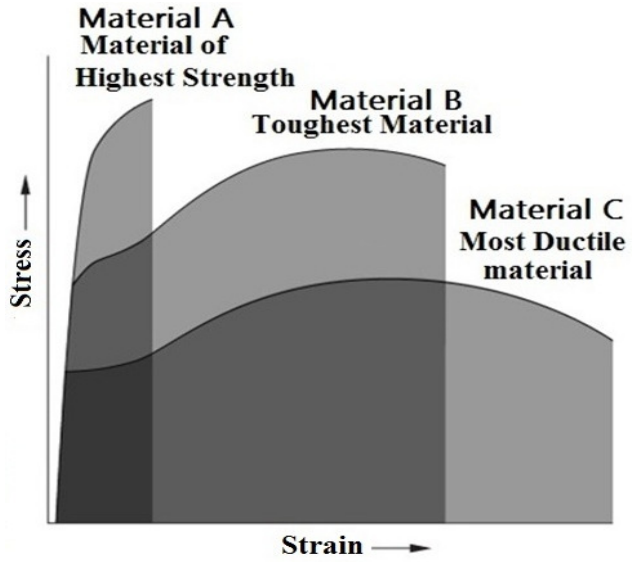


Fig. 1. Graphical Inferences of Strength, Toughness and Ductility

Several researchers have measured the Bone's fracture toughness, and they have reported important effects such as a significant anisotropy, because of which Bone's fracture toughness is lowest for cracking in the longitudinal direction and a decreasing trend of toughness has been observed with growing age [5]. Also a large variation has been observed in measured values of toughness, ranging from 2 to 7 $MPa(m)^{1/2}$. These variations, may be only partially attributed to the above effects, implying that the mechanism of toughness is not a straight forward matter.

The property of the toughness of cortical bone may be attributed to the composite nature of haversian, circumferential, and interstitial lamellae. The structural arrangement or the architecture of a composite anisotropic material of bone finds analogy with the bundle of straws with a plastic stick and it illustrates how the structure outperforms a single uniform isotropic material in resisting. High strain is generated within the periphery of the material and the plastic stick breaks on application of relatively little bending but with the bundle of straws the same mass subjected to the same bending conditions will sustain the strain incurred rather than breaking, as every independent element undergoes relative slip with adjacent elements.

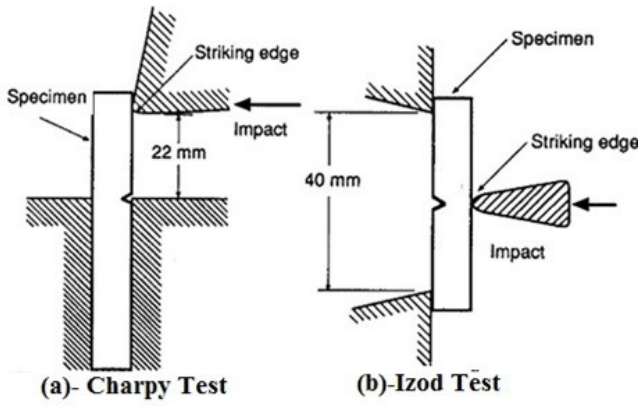
3. EVALUATION OF TOUGHNESS OF BIOMATERIAL

3.1 ENERGY FOR FRACTURE: TOUGHNESS OF BIOMATERIALS

There are various ways for assessing the measurement of Toughness of various Engineering materials. With respect to measure of toughness which has been used in assessing the toughness of bone and may be called as work to fracture [3], defined as the value of work done (fracture energy) per unit area for breaking an specimen (un notched) into two pieces which may be loaded either in bending or tension. By this method material being tested without any premade crack or notch, gives measure of toughness, which is essentially the energy equivalence. It depends on the bone-matrix structure as well as on the distribution of defects (either natural or developed during processing).

3.2 IMPACT TESTING

The basic purpose of impact testing is to measure the materials Toughness or the ability to resist high-rate loading. Conventionally with other engineering materials the Impact Testing is commonly conducted with Charpy and Izod specimen configurations (Fig 2).



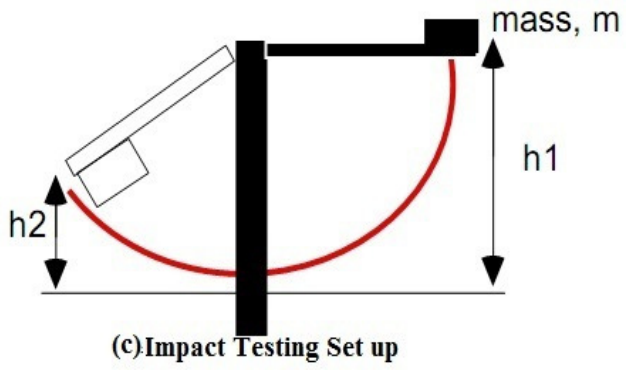


Fig. 2. Impact Testing Set up and Types

3.3 ASTM TEST PROCEDURE

ASTM has proposed standard test methods for measuring the plane-strain fracture toughness in mode I for metallic materials (ASTM E399-90 [16]), and by default for other materials. For the Bone Fracture Toughness Specimens are prepared as per ASTM E-399-83standards, having dimensions of the Lengh,Width and Thickness in the ratios of 8:2:1 respectively. All the faces of the sample are polished upto mirror finish and final dimensions are prepared upto .01mm accuracy. The most widely used specimen configurations for bone are the single-edge notched three-point bend SE(B) and compact-tension C(T) specimens as given in Fig. 3 [17].

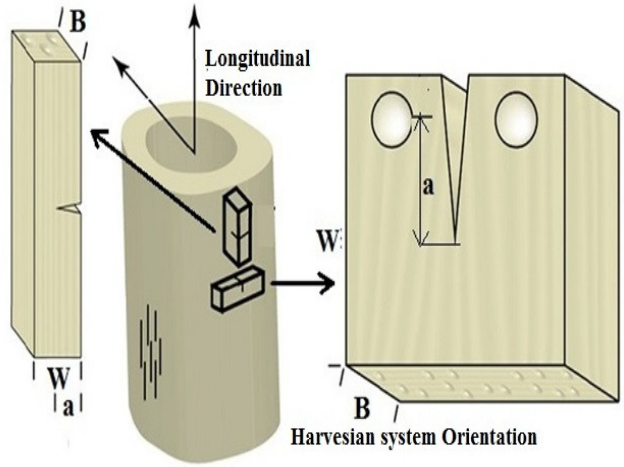


Fig. 3. Sample specimens of a long bone showing the locations where testing location can be harvested from the cortex. Sample test bone has been shown in the transverse and longitudinal directions [2].

4. CONCLUSIONS

It is really important to review the biomechanics of bone from the principles of strain, stress, load, and failure to consider the response to mechanical challenges by modeling and remodeling a successful structure. Various methodologies have been developed to measure the toughness (fracture resistance) of biomaterials like bone acquired from different sources, which include evaluating work to fracture, the fracture toughness with respect to linear-elastic fracture and nonlinear elastic fracture. While Work to Fracture is assessed using an unnotched test procedure in comparison to the fracture mechanics methods which employ notched/pre cracked samples. Procedures to evaluate the value of Fracture Toughness applicable to different situation in order to give reliable results have been established. Substantial research in challenging areas of Fracture Toughness is still on. But even as per the current status in most of the common situations it may be claimed to propose or workable solution to the situation upto great extent.

REFERENCES

[1] Ratner, B.D.; Hoffman, A.S.; Shoen, F.J.; Lemons, J.E. Biomaterials Science: An Introduction to Materials in Medicine. Academic Press, 1996, pp. 37–50.

[2] Ritchie, R.O.; Koester, K.J.; Ionova, S.; Yao, W. Measurement of the toughness of bone: A tutorial with special reference to small animal studies. Bone, 43, 2008, 798–812.

[3] Currey, J.D. Mechanical properties of bone tissues with greatly differing functions. J Biomech, 1979, 12:313–9.

[4] Rubin, C.; Rubin, J. Biomechanics and Mechanobiology of Bone, American Society for Bone and Mineral Research, 2006, Chapter 6.

[5] Taylor, D. The Fracture Mechanics of Bone. Anales de Mecánica de la Fractura, 2006.

[6] Behiri, J.C.; Bonfield, W. Orientation dependence of the fracture mechanics of cortical bone. J Biomech, 1989, 22:863–7.

[7] Kalkwarf, H.J.; Specker, B.L.; Bianchi, D.C.; Ranz J.; Ho, M. The effect of calcium supplementation on bone density during lactation and after weaning. New Engl J Med, 1997, 337:523–8.

[8] Zioupos, P.; Currey, J.D. Changes in the stiffness, strength, and toughness of human cortical bone with age. Bone, 1998, 22:57–66.

[9] Shane, E.; Addesso, V.; Namerow, P.; McMahon, D.J.; Lo, S. Staron RB, et al. Alendronate versus calcitriol for the prevention of bone loss after cardiac transplantation. New Engl J Med, 2004, 350:767–76.

[10] Roodman, G.D.; Mechanisms of bonemetastasis. New Engl J Med, 2004, 350:1655–64.

[11] Vashishth, D. Rising crack-growth-resistance behavior in cortical bone: implications for toughness measurements. J Biomech, 2004, 37:943–6.

[12] Nalla, R.K.; Kruzic, J.J.; Kinney, J.H.; Ritchie, R.O. Mechanistic aspects of fracture and R-curve behavior in human cortical bone. Biomaterials, 2005, 26:217–31.

[13] Lane, N.E.; Yao, W.; Balooch, M. et al. Glucocorticoid-treated mice have localized changes

in trabecular bone material properties and osteocyte lacunar size that are not observed in placebo-treated or estrogen-deficient mice. J Bone Miner Res, 2006, 21:466–76.

[14] Yao, W.; Cheng, Z. et al. The degree of bone mineralization is maintained with single intravenous bisphosphonates in aged estrogen-deficient rats and is a strong predictor of bone strength. Bone, 2007, 41:804–12.

[15] Patel, N.R. A Review on Biomaterials: Scope, Applications & Human Anatomy Significance. International Journal of Emerging Technology and Advanced Engineering, 2012.

[16] ASTM Standard E-399. Standard test method for linear-elastic plane-strain fracture toughness KIc of metallic materials. West Conshohocken, PA: American Society for Testing and Materials, 2006.

[17] ASTM Standard E-1820. Standard test method for measurement of fracture toughness. West Conshohocken, PA: American Society for Testing and Materials, 2006.