TORSIONAL STRENGTH EVALUATION AND EXPERIMENTAL VALIDATION OF FEMUR BONE

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Abstract: Human Bones are very important elements of body. A bone is a rigid organ that constitutes part of the vertebral skeleton. Bones support and protect the various organs of the body. Bones comes in a variety of shapes and sizes and has complex internal and external structure. During normal daily activities, the skeletal system is subjected to a Complex System of loading exerted by the forces of gravity and the muscles attached to the bones. Such loading modes include tensile, compressive, bending, and torsional forces applied to the bones of the skeletal system. Therefore, in evaluating the tolerance limits of bones, it is important to determine the failure behavior of bones under all of these loading Conditions. In order to determine mechanical properties of bones and to study the effect of loading on bones a reliable design and test procedure is required to guarantee the accurate desired output. The proposed work is aimed to investigate correlation between HU & STRENGTH of Femur bone and evolution of femur by torsion testing setup. CT scan of femur bone has to be done and obtained data is taken into DICOM format. Obtained data is imported in MIMICS software, MIMICS software automatically stacks slice in manner of selection. Area and Hounsfield unit of each slice is calculated. Based on this calculation Density and Modulus of elasticity is calculated for each slice using expression given in user manual of MIMICS Software. Design and manufacturing of Torsion test setup has to be done in order to determine mechanical properties by torsion test.

***Index Terms* - Torsion, Femur Bone, Fixture, MIMICS software.**

I. INTRODUCTION

The femur is a longest bone in human body, it is located in thighs the upper part of bone forms hip joint while lower part of bone forms knee joint , during normal daily activities, the femur bone is subjected to a complex System of loading exerted by the forces of gravity and the muscles attached to the bone. Such loading modes include tensile, compressive, bending, and torsional forces applied to the bones of the skeletal system, if these forces increased beyond certain limit the chances of bone breaking or cracking are increases this is called fracture, mostly fracture of femur occurs in 3 areas:

I. Head / Upper part of bone.
II. Main shaft of bone.
III. Lower end near the knee.

Fracture in femur is mainly caused by body weight of person (when in falling condition), collision with an object, motorcycle accident fall from high place, injury during extreme sports. Therefore, in evaluating the tolerance limits of bones, it is important to determine the failure behavior of bones under all of these loading Conditions.

The shear stress-strain response of materials can be extremely important in the design, analysis and manufacture of a wide variety of products and components which are loaded primarily in shear or torsion. When the applied loadings are primarily shear in nature, the shear modulus of elasticity and shear yield strength must be known in order to apply the usual closed form equations commonly used in engineering design and analysis. These properties are determined from the shear stress-strain diagram which is most commonly measured according to an ASTM torsion test. Where a material specimen of solid or hollow round cross section is twisted in a torsion testing machine as the applied torque and angle of twist are recorded simultaneously. The torque-twist diagram is constructed from these data, and elementary mechanics theory is then used to construct the shear stress-strain diagram. Following are some types of Torsion tests available.

II LITERATURE REVIEW

1. **Mechanical properties of Bone by Yuehuei H. An, M.D. Robert A. Draughn, D.Sc.**
   Bone is a heterogeneous tissue because its basic components are assembled in different ways, the main structural determinants being the type of bone, age, loads, and metabolic activity. The type of bone essentially depends on the density of its structures, which ranges from a very compact state in cortical bone to a sponge like appearance in cancellous bone, and from a compact aggregation of collagen fibrils in lamellar bone to their comparatively loose state in woven bone. Age chiefly induces a transformation of woven bone into lamellar bone soon after birth, and a late, almost physiological loss in bone volume with alterations to connectivity. The mechanical functions are responsible for the maintenance of the architecture of bone, and the metabolic ones for its renewal1; both are mediated by the various aspects of bone remodeling, which induces the erosion and reconstruction of trabecular segments in spongy bone, and of osteons and other lamellar structures in compact bone.

2. **Relations of mechanical properties to density and CT numbers in human bone J.Y.Rho, M.C. Hobatho and R.B. Ashman:**
In this research paper mechanical properties of cortical and cancellous bone from eight human subjects were determined using an ultrasonic transmission technique. Raw computerized tomography (CT) values obtained & scans of the bones in water were corrected to Hounsfield units. The correlations between CT numbers und mechanical property estimated from cortical bone were found to be low (r2< 0. Z), while these relationships for cancellous bone were found to be higher.
These results are useful in predicting mechanical properties only for cancellous bone. Poor correlations found between modulus in the radial or circumferential direction.

3. **Biomechanical Characteristics of the Bone by Antonia Dalla Pria Bankoff :**
The research in bone biomechanics mentioned in this section contributed to show the importance of this area of study and brought brief discussions on the bone tissue and its incorporation in the biomechanical aspect of human skeletal and loco motor system. The information contained in this study by the authors was a cited research and placed the bone tissue (histology, anatomy, biomechanics and kinesiology) as a material adaptive level of loads.

4. **A linear-actuated torsional device to replicate clinically relevant spiral fractures in long bones by W Brent Edwards and Karen L Troy:**
For better understanding of the mechanisms of fracture we have to carry out biomechanical tests of long bones loaded in torsion to failure a device was fabricated for performing torsional tests of long bones. The principal operation of the device was to transform the vertical displacement of a material testing machine's linear actuator into rotational movement using a spur gear and rack system. Accuracy and precision of the device were quantified using cast-acrylic rods with known torque–rotation behaviour.
The device is developed, validated, and applied a linear actuated torsional force. The device is accurate, precise, and capable of replicating clinically relevant spiral fractures in long bones. Although the application of this article dealt specifically with spiral fracture of the proximal tibia, the device presented is applicable to any torsional testing of long bone when only a linear actuator is available.

III THEORY

3.1Theoretical framework

Figure 1 shows the hollow cylinder under torsion. A segment from a long bone is approximated as a hollow cylindrical shaft made from a homogeneous, linear elastic material. Such a shaft might have a certain inner radius, r_i, an outer radius, r_o, and a length, L. If one end, A, of the shaft is fixed, and a torsional force, T, is applied to the opposite end, B, then end B will rotate in its own plane through some angle with respect to end A.

To find the shear stress, in the material at any radius within the cross section of the Shaft Eq. 1 is used.
The maximum shear stress, □max is given by Eq. 2.
The relative angle between ends A and B can be calculated by Eq.3.
Polar moment of inertia J is is given by Eqn.4

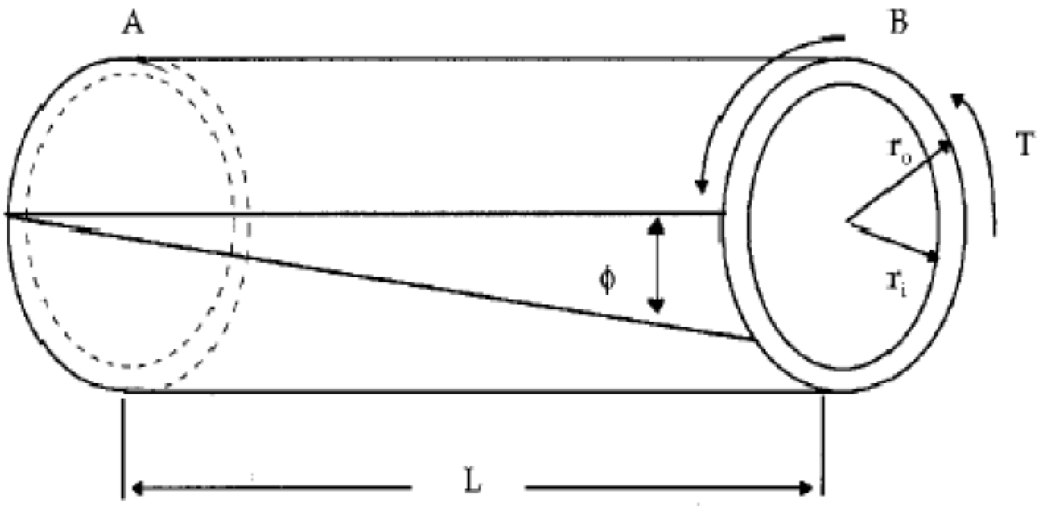

Fig.1 Cylindrical bar under torsion

Equations

$$\tau = \frac{Tp}{J}$$

$$\tau_{max} = \frac{Tro}{J} \quad (2)$$

$$\emptyset = \frac{TL}{JG} \quad (3)$$

$$J = \frac{ro^4 - ri^4}{2} \quad (4)$$

3.2 Types of torsion testing fixtures

3.2.1 Vertically gripped bone in clamp

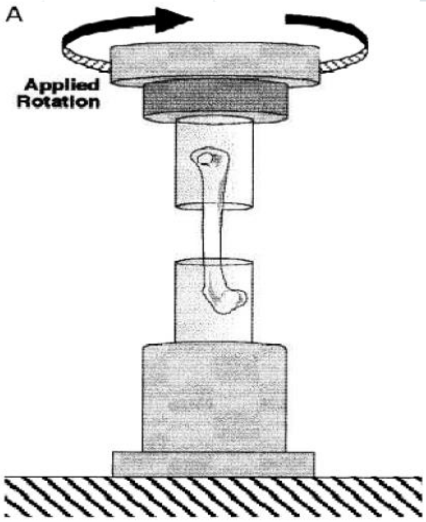

Fig.2 Vertically gripped bone in clamp

Figure 2 shows vertically gripped bone in clamp. As per the set up idea to mount the bone vertically and apply torque on the vertically mounted bone, the lower part of bone is fixed and the upper part is rotated by applying motor torque .The idea was fair enough but there was inconvenience to hold the bone vertically. Hence this idea to hold the bone vertically was not an appropriate way to hold the bone.

3.2.2 Horizontal bone holding device

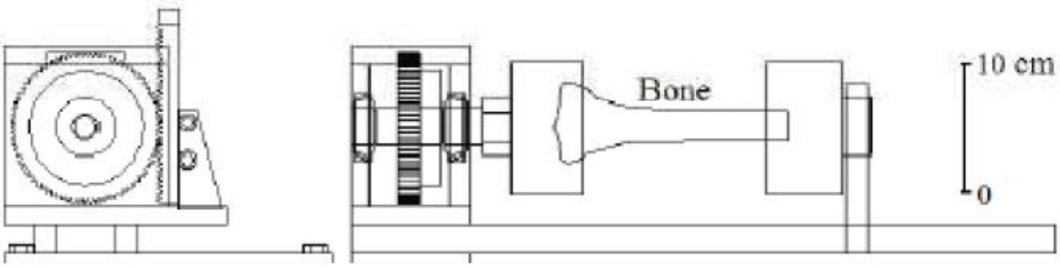

Fig.3 Horizontal bone holding device

Figure 3 shows horizontal bone holding device. In this principal operation of the device is to transform vertical displacement of the material testing machine's linear actuator into rotational movement by way of a steel spur gear and rack system. The spur gear is mounted to, and housed within, a cast aluminum frame using a steel tapered-roller bearing and roller assembly. The cast aluminum frame is bolted to the material testing machine's working base, along with a chrome-moly rectangular bar directed orthogonal to the machine's linear actuator.

Testing sample is attached to system with help of two aluminum pots; the proximal pot is coupled to the spur gear due to this it rotates, while the distal pot is attached to rectangular bar which is fixed. The position of the distal pot is adjustable along the length of the rectangular bar. The electric motor and gear reduction unit is used.

3.2.3 Horizontal chuck holded bone

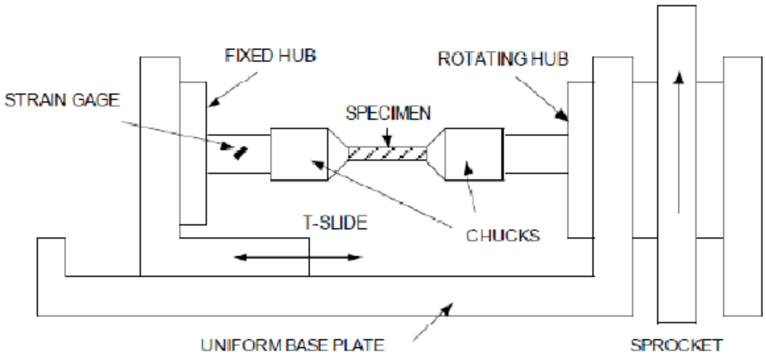

Fig.4 Schematic of torsion test machine

Figure 4 gives idea of torsion test setup. This provides low cost solution for perform torsion test. Basic concept of machine is shown in figure. The specimen was mounted between a non-rotating fixed hub assembly and a rotating hub assembly which was connected to a drive train. The non-rotating hub was mounted on a T-slide to allow motion along the axis of the specimen to prevent axial loads from developing as the length of the specimen decreased during twisting. The non-rotating hub would also include a strain gauge torque sensor used to measure the applied torque. The rotating hub would be driven using a drive sprocket connected to the drive train. The specimen angle of twist would be determined by measuring the rotation of the rotation hub. The bone specimen is mounted horizontally on the testing setup.

MIMICS SOFTWARE:

MIMICS is an image processing software for 3D designing and modelling. The software is used for 3d design and modelling for making parts for additive manufacturing, medical and dental industries. The generated 3D models can be used for variety of engineering applications.

Mimics can calculate 3D model surfaces from stacked image data such as CT scan, MRI scan and ultrasound. These files are stored in STL format.

IV.RESEARCH METHODOLOGY

4.1 Review of literature

Before making the fixture for torsion testing of femur bone we are going initially through the research work done for testing and determining various properties of femur bone. We have got some basic idea about the available fixtures, the types of fixture which have already made for testing of femur bone.

4.2 Selection of Bone

Femur bone is selected for torsion test because it is longest bone in human body and during daily activities the bone is subjected to complex loads like axial load, torsional load. Due to excessive loading or in case of sudden fall of a human, or during any sport injury it may get fail. That means a crack or permanent breakage of the bone. So, it is necessary to determine the strength of the bone.

4.3 CT Scan of Bone and data conversion in DICOM format

After selecting the femur bone we perform CT scan of the bone. In CT scan w will find the various bine properties like Bone Mineral Density (BMD), Bone Mineral Content (BMC). These will help us to determine the strength of femur bone. The CT scan data is converted in DICOM (Digital Imaging & Communications in Medicine) format. Which is a standard input for MIMICS software.

4.4 Torsion test fixture setup

To perform a torsion test a convenient and optimized setup will be made. The setup is designed in SOLIDWORKS design software, this setup will be manufactured with using mild steel bars for minimizing cost. The setup will be made adjustable so that in future with help of this setup we can perform tests on other bone with implementing small changes. Torsion test performed with using this setup. The specimen of human femur cortical bone is firmly hold between two clamps. One end is fixed and other end is movable, according to specimen length the clamps are adjusted and fixed with the help of bolts. Rotating clamp is connected to hydraulic motor, after proper clamping of bone hydraulic motor is started. With the help of pressure sensor the value of pressure at the breaking point is measured.

V. RESULTS AND DISCUSSION

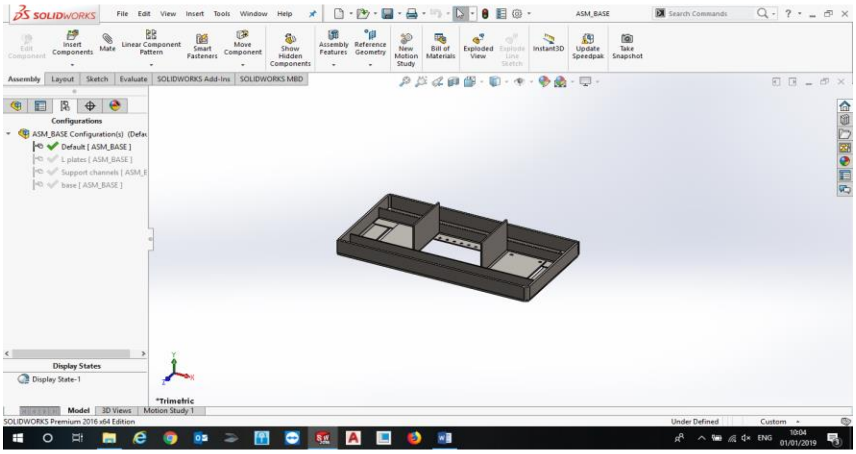

Fig.5 Basic idea of making fixture

Figure 5 gives us the basic idea of designing the fixture. One end of bone is fixed and other is holded in chuck will be rotated with the help of hydraulic motor.

For strength evaluation of bone we are using "MIMICS" software.
The fixture is designed in "SOLIDWORKS" software.

CONCLUSION

1. BMD of bone can be found by using various methods, E.g. CT scan data
2. Model developed in this investigation can be used to find BMD and HU directly by considering value of torsional strength of bone.
3. By using this experimental we can find different properties of bone, which are helpful in medical sector for designing and manufacturing of implants, research and many other fields.
4. We are trying to make testing fixture universal, which can be later used for testing of other bones with implementing small changes.

VI. ACKNOWLEDGMENT

Prof. S.G. Ganiger thanks for giving me the opportunity to do this wonderful project of "Strength evaluation and experimental validation of femur bone", who also helped me in my project. I came to know about so many new things I am really thankful. The study has indeed helped me to explore more knowledge avenues related to my topic and I am sure it will help me in my future.

REFERENCES

[1] W Brent Edwards, 2012. A linear actuated torsional device to replicate clinically relevant spiral fractures in long bones, 226(9): 729-733.

[2] Michael D. Brodt, 1999. Growing C57Bl/6 Mice Increase Whole Bone Mechanical Properties by Increasing Geometric and Material Properties, 2160-2162.

[3] Antonia Dalla Pria Bankoff, Biomechanical characteristics of the bone, 62-83

[4] J. Y. Rho, M. C. Hoabto and R. B. Ashamn, 1994. Relations of mechanical properties to density and CT numbers in human bone. 348-351.

[5] Yuehuei H. An, M.D. Robert A. Draughn, D.Sc., Mechanical properties Of Bone.

[6] Mr. Borude S.C., Prof. Biradar N.S., Review Paper on Design and Development of Coupling Torque Endurance Test Machine with Variable Torque and Chamber Adjustment.

[7] Þröstur Pétursson, Benedikt Magnússon, Benedikt Helgason, Bone and muscle assessment in patients undergoing total hip arthroplasty using HU based analysis.

[8] MA303-ART01-D v1 LAB MODULE – TORSION OF BONE, 2017.

[9] S. B. Roberts, S. K. Pathak, Torsional behavior of the human femur.

[10] Bosemark P., Isaksson H., 2012. Three point bending – vs torsion-testing of BMP-treated rat femora.

[11]C. H. Turner, T. Wang, 2001. Shear strength and fatigue properties of human cortical bone determined from pure shear stress.