DYNAMIC PROPERTIES OF HUMAN CANCELLOUS BONES

Sudipto, Mukherjee
Anoop, Chawla
Kartik, Marwah
Lucky, Grover
Joel, Keishing
Mechanical Engineering, Indian Institute of Technology Delhi
India
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ABSTRACT

A micro drop system consisting of an impactor supported by twin parallelogram linkages was designed to enable guided drop height as low as 10mm. The system has been used to measure dynamic compressive response of human cancellous bone for strain rates of 135/s, 150/s and 175/s. The percentage variation of Young's modulus from its mean value of 0.083GPa obtained at these strain rates is 54.5%, which is significant, suggesting that bones become stiffer during severe impacts.

INTRODUCTION

With the rapid economic and social development in 21st century, the incidence of road accidents has increased tremendously. The Global Burden of Disease Report, published by the World Health Organization, predicts that road traffic accidents are projected to rise from the ninth leading cause of death globally in 2004 to the fifth in 2030 (WHO, 2004). In developing countries like India, 80,000 people are killed annually on roads, amongst whom 70-80% are vulnerable road users (Mukherjee, 2003). With continuous advancement in computer technology and numerical methods, computer simulations have become an important tool in analyzing biomechanical response and understanding injury mechanisms. Finite element analysis became a standard tool for the evaluation of bone mechanical properties. FE models, with realistic geometry and accurate material properties can predict the human body response for different loading and boundary conditions. These models can be used to improve the design of vehicle structure by predicting the level of injury during vehicle-pedestrian collision. The process of determining the geometry of human body models using CT and MRI is fairly well established, but rate dependent material properties are scarce. This paper describes a methodology to ascertain the mechanical properties of cancellous bones under compressive loading at strain rate up to ~175/s for which a micro-drop system was designed.

RESEARCH OBJECTIVE

The objective of this study was to characterize the dynamic compressive response of human cancellous bone at strain rates representative of loading during car impacts. For this a compliant drop mechanism was designed to record the stress and strain variations at the desired strain rates and estimate the modulus of elasticity of cancellous bone specimens.

DESIGN OF COMPLIANT MECHANISM

The requirement of the drop mechanism is that the impactor moves vertically in a straight line. A double parallelogram linkage generates a straight line motion without change of orientation. The impactor is guided by two such linkages arranged symmetrically on either side (See Figure 1).

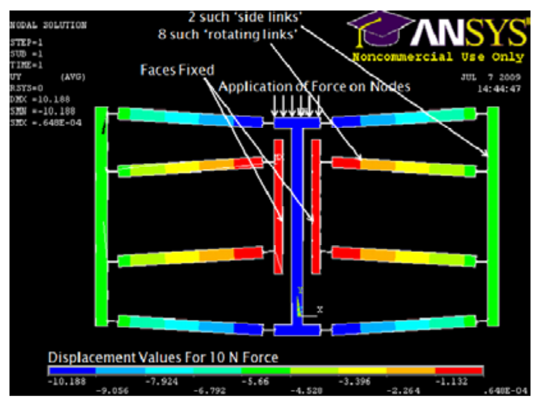

Figure 1. Compliant mechanism showing parallelogram linkages and application of force.

A key requirement is to minimize dissipation of energy in traverse as the specimen is of thickness of the order of 1mm. Use of compliant joints eliminates wear and frictional losses and ensures that the dynamics of the joint are negligible during impact. Use of revolute joints would dissipate energy due to friction and secondary impacts within the revolute joints. Hence compliant joints are used (See Figure 2).

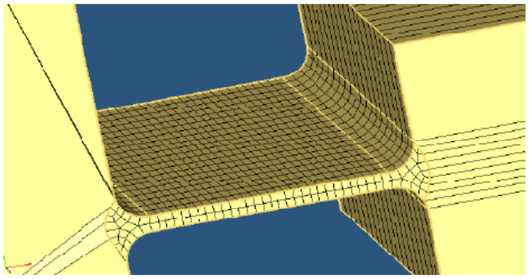

Figure 2. Meshing at the compliant joint.

Specimen Parameters and Design Calculations

The specimen to be tested is a human cancellous bone. Cylindrical specimen with properties and dimensions as given in Table 1 was to be used. These values were used initially as estimates to design the mechanism.

Table 1.
Parameter values related to testing

Property	Value	Symbol
Strain rate	200	$\dot{\varepsilon}$
Strain	3 % = 0.03	ε
Height of specimen	2 mm	l_o
Diameter of specimen	10 mm	d_o
Young's modulus	0.2 GPa	$E_{specimen}$
Cross-sectional area	$7.85\text{x}10^{-5}\ m^2$	A_o
Volume of specimen	$1.57\text{x}10^{-7}\ m^3$	V_o
Amount of deformation	60 µm	

The energy absorbed by the specimen is calculated from the estimate of the Young's modulus of the bone along with the bone dimensions and strain in the bone. The velocity of impact is calculated from strain rate and is assumed to be constant during the impact. By fixing the impact velocity, the drop height of the impacting mass is ascertained. For this the energy absorbed by the specimen is set to be 5% of the energy carried by the dropping mass/impactor. Drop mass is estimated from the energy requirement.

EXPERIMENTAL SETUP

The test set-up consists of an eye bolt and a turnbuckle attached to the top platen of the outer frame (See Figure 3) to raise the drop mass. A load cell transducer (ISOTRON Force Sensor, Model 2311-10) capable of measuring dynamic forces up to 2200N, with an output sensitivity of 10mV/lbf and a frequency response of 75kHz is mounted below the bottom platen and is used to measure the force-time history during the test (See Figure 4).

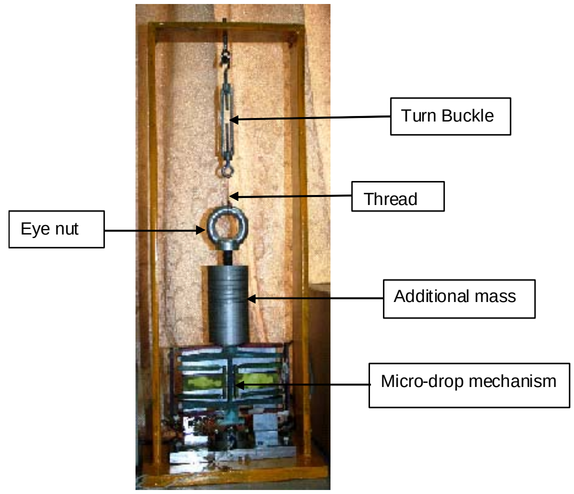

Figure 3. Micro-drop set up.

The additional mass is glued to the upper part of the micro-drop mechanism (See Figure 3). An arrangement is made with an eye nut and additional mass for lifting up the impactor with the help of turn buckle and thread. The webs of the compliant joint are strain gauged and bridged. Bone specimen is mounted on the top of the load cell (See Figure 5) using accelerometer wax for impact testing.

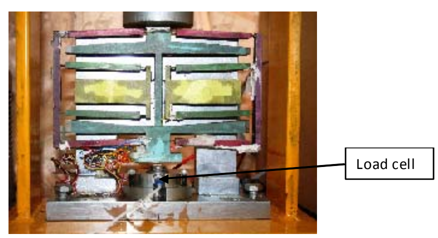

Figure 4. Load cell inside the specimen subassembly.

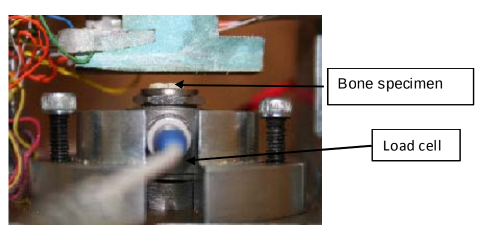

Figure 5. Bone specimen on the load cell.

PREPARATION OF BONE SPECIMEN

Specimen preparation, by grinding the specimen flat, is needed to have a good contact between impactor and specimen. Also, the specimen thickness is to be machined to desired values (See Figure 6).

Tests are performed in an unconfined condition, that is, the specimens are allowed to expand freely in the lateral direction. Unconfined tests are preferred so as to reduce the number of contact surfaces and the friction coefficient between the specimen and the constraining surfaces as it may lead to increase the uncertainties in the experiment.

Figure 6. Bone specimen after machining.

Figure 7. Experimental Setup.

The displacement measurement system using the strain gauges is calibrated by raising the impactor to a specified height. To start the test, the thread is burnt to free the impactor. The displacement and load data is recorded on two channels of a oscilloscope. The entire experimental setup is shown in Figure 7.

RESULTS

The test is conducted on the dry humerus bone specimens with dimensions shown in Table 2 and **Error! Reference source not found.**. The experiment is done at strain rates of 135/s, 150/s and 175/s. The forces on the specimen (recorded via the load cell beneath it) and displacement of compliant mechanism (recorded via strain gauges put on the compliant joints' webs) were recorded synchronously. Time *t* = 0 corresponds to start of bone.

Table 2.Experimental parameters 1

Thickness (mm)	Diameter (mm)	Strain Rate (/s)	Velocity (mm/s)	Drop Height (mm)	Mass (kg)
1.7	5	135	229.5	2.7	3.21
1.7	5	150	255	3.3	2.60
1.7	5	175	297.5	4.5	1.91

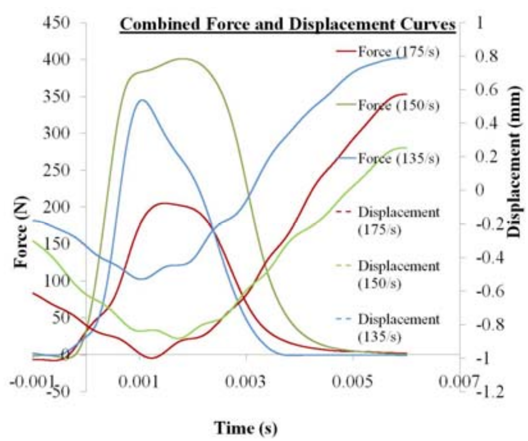

Figure 8. Combined force and displacement plot for strain rate of 135/s, 150/s and 175/s (Specimen information in Table 2).

The displacement v/s time curve shown in Figure 8 and **Error! Reference source not found.** represents bridge output from the strain gauges mounted on the webs of the compliant joints. As the impactor moves downwards the displacement reading reduces. The displacement value at the neutral position is 0 mm and negative below this position. The force v/s time curves represent the readings from the dynamic load cell kept under the bone specimen. The impact on the bone is below the neutral position and the force values start to increase. The force reaches a maxima corresponding to a minima in the displacement. Subsequent to this the impactor hits the catching plates (meant to limit the compression in the bone specimen) and bounces off. This results in the force dropping down and the displacement increasing again.

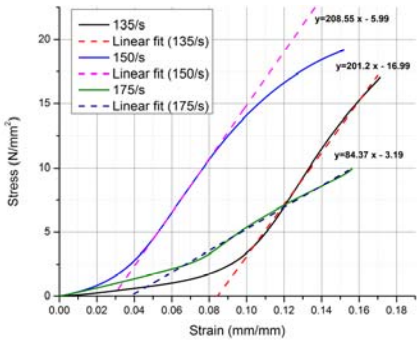

Figure 9. Combined stress-strain plot for strain rate of 135/s,150/s and 175/s (Specimen information in Table 2).

The time history curves were filtered and stress-strain curves for different loading conditions (i.e. varying strain rate) and different specimens were obtained from the geometric parameters. The stress-strain curves were observed to have a toe region followed by a linear region. Between the loading rates of 135/s and 150/s, the change in stiffness after the toe region is not significant, but the toe region decreases. The stiffness for the highest strain rate, 175/s is estimated to be about 85 MPa, which is lower than the value of about 200 MPa estimated at 135/s and 150/s.

CONCLUSION

A compliant mechanism was designed to carry out impact tests on cancellous bones at strain rates up to 175/s. The mechanism was fabricated along with suitable attachments to facilitate testing. The testing was done at strain rates which are typical in vehicle and pedestrian collision (50-200/s). The variation of stress with strain was ascertained at these strain rates. A distinct toe region is visible in stress-strain plots. The Young's modulus of dry cancellous bones is found to lie between 0.08 GPa and 0.2GPa (See Figure 9). The cancellous bones exhibit

The proposed setup is seen effective in determining response of isolated bone specimen in direct drop tests. There is need to conduct more tests, from different regions as well as from similar structure to infer the characteristics fully including study of the variation due to apparent density of the bone.

REFERENCES

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