Virtual Labs, Real Data

Sample preparation and data reduction – Turkey tibiotarsus

Theoretical and Applied Mechanics

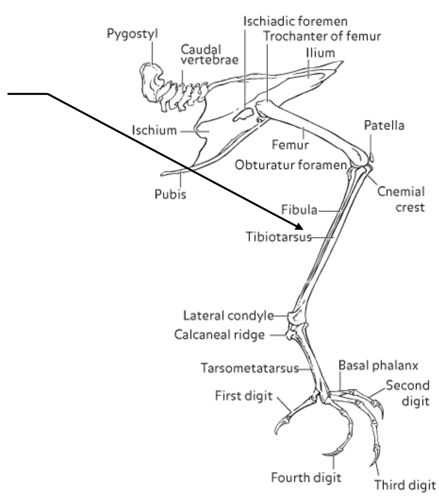
CORNELL

Outline

- Sample preparation, mounting and measurement
- Definition of equivalent circular cross section
- Data Reduction
  - Shear modulus
  - Fracture strength

Sample preparation

- Bone used is the drumstick, or tibiotarsus
- Purchased from a turkey farm
- Bones were kept frozen until preparation
- Two types of bones were prepared:
  - Wet bone
  - Dry bone



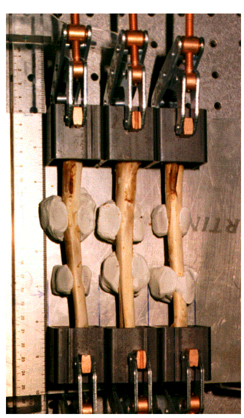
Avian leg structure,
http://cm27personal.fal.buffalo.edu/birds/anatomy/internal/FIG_02_06.html

Wet vs. dry bone preparation

- **Wet bone**
  - All muscle and cartilage are removed
  - Bone is kept moist in a saline solution
  - Bone is tested immediately after preparation
- **Dry bone**
  - Bone is cleaned, and then boiled for about 1 hour
  - Remaining muscle and cartilage are removed and bone is boiled for another hour in a water and bleach solution
  - Bone is kept in a dry environment for two weeks until testing

Sample mounting

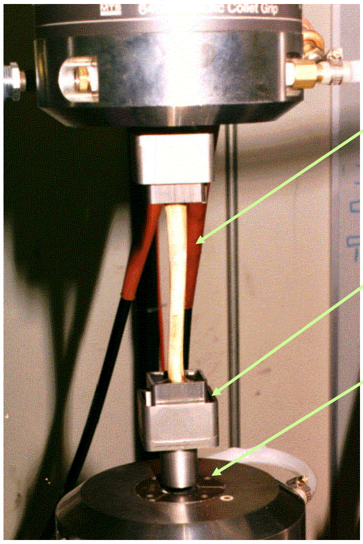
Bones are placed into sockets



Bones aligned with socket center, held in place with clay

A potting compound is poured into sockets. After it is cured, samples are flipped over and other end is bonded

Mounting turkey bone in test machine

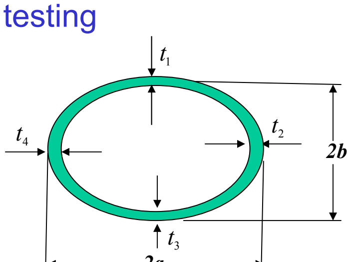


Once sample is bonded into the sockets and measured….

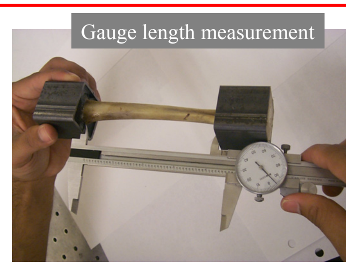
Sockets are placed into square grips that are held by the hydraulic collet grips

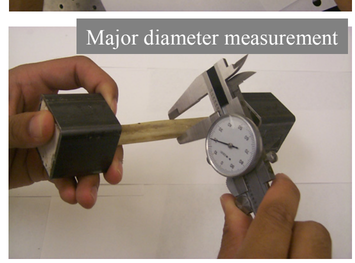
Sample measurement

- Measure gauge length
- Measure major **(2*a*)** and minor diameter **(2*b*)**
- Thickness **(*t*)** at four locations measured *after* testing

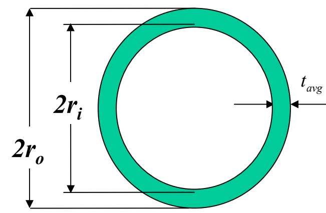


Schematic cross section of actual bone





Approximation of Cross Section



$$t_{avg} = \frac{t_1 + t_2 + t_3 + t_4}{4}$$

$$r_0 = \frac{(a+b)}{2}$$

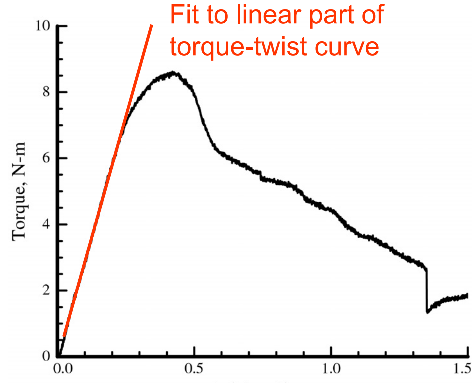
$$r_i = r_0 - t_{avg}$$

$$A = \pi \left(r_0^{\,2} - r_i^{\,2}\right)$$

$$J = \frac{\pi \left(r_0^{\,4} - r_i^{\,4}\right)}{2}$$

Data reduction: Torsional stiffness

- Fit a straight line to linear portion of curve
- Torsional stiffness, k_{total}, , is equal to the slope of this line
- Note that sample stiffness is so low that is not necessary to correct for finite test machine stiffness (see slide 6 of procedure for engineered materials), thus $k_{sample} = k_{total}$

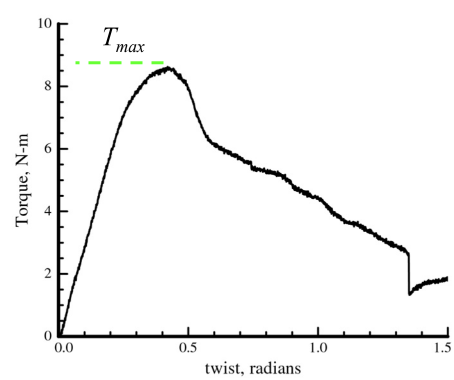


Data reduction:
Shear modulus

- Calculate shear modulus from $G=kL/J$ *(see slide 7 of theory talk) where* L is the gauge length, and $k=k_{Sample}$
- Dimensions needed for J, L are given in header of data files.

Data reduction:
Fracture strength

- Bones may begin to micro fracture causing non-linearity in torque-twist curve prior to ultimate failure.
- Compute ultimate shear strength, τ_u, from $\tau_u=T_{max}\, r_O/J$



Summary

- Wet bone samples are prepared by cleaning and are kept moist until testing
- Dry bone samples are prepared by cleaning and boiling, then tested two weeks later
- Bones mounted into sockets
- Sockets held in test machine
- Idealize as circular cylindrical cross section
- Estimate shear modulus and shear strength.

Slide 1

Here we will review the preparation, measurement and data reduction for tests of the turkey bones. Because the cross section of the bone is not circular, the measurement and data reduction procedures are somewhat different than for the circular cross section samples of aluminum, cast iron and PMMA.

Slide 2

We use the tibiotarsus, also known as the drumstick. The drumsticks were purchased from a turkey farm. To ensure freshness, bones were frozen in a commercial freezer. Two types of bones were tested, wet bones and dry bones.

Slide 3

In preparing the wet bones, all muscle and cartilage are removed. The bones are then submerged in a saline solution made of distilled water and four salts and are kept wet until testing. The dry bones are prepared in a different manner. After cleaning, the bones are boiled for an hour, cleaned again, and then boiled for another hour in water and a small amount of bleach. The bones were tested two weeks later. Only the left tibiotarsus was tested.

Slide 4

Mounting the bones for testing is a challenge since the bones are not uniform cylinders. Our method is to bond the ends of the sample into square sockets using a potting compound. First one end of the bone is placed into a socket. Using clay, the bone is aligned by eye so that it lies in the center of the socket. Next the other end is placed in a socket and the entire bone aligned and held in place with clay so that it is in the center of both sockets. The sockets themselves are aligned with a metal ruler to ensure that they are parallel. Once aligned they are clamped to a base plate. The entire assembly of sockets, base plate and bones is tipped on one side and the potting compound is poured in to fill the space between the bone and socket. Once it has cured, the assembly is turned over and the other side is filled.

Slide 5

The sockets holding the bone cannot be mounted directly into the testing machine, thus they are placed into square grips that slide over the sockets. The grips have a circular shaft that can be held in the hydraulic collet grips.

Slide 6

The sample is measured before and after testing. Before testing the gauge length, defined as the distance between the sockets, is measured as are the major and minor diameters of the bone at the mid-point of the bone. The thickness is measured after testing. We measure thickness at four locations and report the average value.

Slide 7

The exact analysis of the bone is quite involved and should incorporate the actual shape and dimensions of the bone including its lengthwise variations. Although researchers are working on such approaches, biomedical scientists often take a somewhat simpler approach. In this approach, variations of the cross section along the length of the bone are ignored. To further simplify the analysis, an equivalent circular cross section is defined. The outer radius of this equivalent section is the average of the major and minor radii. The inner radius is found by subtracting off the average thickness from the outer radius. The cross sectional area and polar moment of inertia are found by using the standard formulae for circular cross sections.

Slide 8

The torsional stiffness is found in the same manner as for the engineered materials. The torque-twist curve is plotted over a small range. The linear portion of the data is extracted, and a straight line is fit to this data. The slope of the line gives the torsional stiffness. Note that in contrast to the tests of aluminum and iron, the stiffness of the bone is so low relative to the test machine stiffness that correction for finite test machine stiffness is not needed.

Slide 9

The shear modulus can be determined using the relation between shear modulus, stiffness, length and polar moment of inertia outlined in the theory talk, and in your textbooks. Note that due to the approximations made regarding the shape of the bone, this value should be thought of as only an approximation. Note also that one might expect G to vary from one sample to the next due to natural variations between individual animals.

Slide 10

The shear fracture strength can be estimated based on the maximum torque reached in the experiment. The shear strength, tau ultimate is given as tau ultimate equals max torque times outer radius divided by the polar moment of inertia, J.

Slide 11

In summary the wet turkey bones are prepared by cleaning and are kept moist until testing. Dry bones on the other hand, are cleaned, boiled and allowed to dry for a period of two weeks. All bones are bonded with a potting compound into sockets that can be held in the testing machine. The samples are analyzed as though they were circular section cylinders. The equivalent inner and outer radii of the equivalent sections are found by matching the cross sectional area and polar moment of inertia of the actual cross section with the idealized, equivalent circular section. Approximate values for the shear modulus and shear strength of the bone can then be determined.