BE 209 – Group BEW6
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Impact Strength of Chicken Bones

INTRODUCTION:

Bone fractures are common occurrences of everyday life. During car accidents, for example, strong impact to a region of a bone can cause fracture at the particular area. Bone fractures are often painful and take a considerable amount of time to heal. Studies based on simulations of impact collision of bones can lead us to findings valuable in preventing the occurrence of bone fractures.

In this experiment, we study the effects of impact on chicken bones. We hope that chicken bones are similar enough in property to human bones that our findings will be applicable to human cases of bone fractures. Through the simulation we hope to find the amount of energy required in breaking a chicken bone. It is to our understanding that the more energy applied, the more likely that a bone will break. Thus by finding out the amount of energy with which a bone will break, it is possible to design measures to prevent the impact energy from reaching to the critical level and causing fracture. In addition, we also hope to determine whether or not breaking energy is a property of the material or of bone. We hypothesize that breaking energy is a structural property, with greater breaking energy required when the area in contact with the bone is greater. Knowledge of the correlation between the energy required and the area of force applied is applicable to the design of preventive measures, such as a seat belt, that utilizes area to offset effects of impact strength.

METHODS & MATERIALS:

First we took the necessary measurements for calculating the center of mass of the swing arm of the impact pendulum apparatus. By means of a pull-scale, we measured the amount of force supplied at the end of the swing arm. The force was measured with the swing arm positioned 90° from position 0, where position 0 was taken to be the free hanging position of the swing arm. At position 0, $\theta=0°$. Positive angles were taken to be angles to the left of position 0 and negative angles were to the right. "The right of position 0" was defined as the direction in which the wedge end of the swing arm faced when it was at position 0. Next, we measured the distance from the top of the swing arm to the point at the end of the swing arm where the force supplied by the arm was calculated. This point was the approximate midpoint of the wedge end of the arm. The mass of the swing arm was given as 1041g.

Second, we used a leveling device and paper towels to wedge under the apparatus in order to level the apparatus. Next, we collected measurements for the calibration curve for the impact pendulum apparatus. We positioned the swing arm at 6 angles: ±90°, ±45°, and ±30°. The swing arm was positioned at each respective angle with the aid of a protractor. The output voltage, which was measured by Lab view at each angle, was recorded. This data was used to construct a plot of angle of rotation versus voltage.

Next, the five chicken legs were removed of their meat and tissue by means of a scalpel. The average outer diameter of each bone was taken with a caliper at the approximate midpoint of each sample. The midpoint was subsequently marked. The average outer diameter was calculated by averaging the maximum outer diameter and the minimum outer diameter. The average outer diameter of the samples was 8.61mm. The outer diameters ranged from 7.95mm to 9.90mm.

An impact pendulum apparatus was used to fracture the bones. A voltage divider in the pendulum monitored the angle of the swing arm. Before testing the samples, we ran a few trial tests with pencils to ensure that the apparatus and the Lab view program were working properly. After the trial tests were run, each bone labeled specimens A through E was tested. First, the bone was place at a position 0 so that the flat side faced the line through which the swing arm acted. The horizontal length of the flat side of the bone that would come in contact with the swing arm was also measured. The average length of contact was 9.69mm and the values ranged from 8.90mm to 10.60mm. The Lab view program was started. Data was collected at 100 data points per second. The swing arm was positioned at θ_i, which is the initial angle of the swing arm prior to release. θ_i was approximately 89° and was the same for each trial. The positioning of the swing arm at θ_i was accomplished by elevating the swing arm so that the voltage reading for θ_i was the same from trial to trial; the angles of rotation are proportional to the voltage readings. Before release, the swing arm was held in place by means of a ruler. To begin the trial, the ruler was quickly slapped to the side. This released the swing arm which proceeded to contact the bone at position 0 and fracture it and then swing to the right of position 0 to θ_f, which is the maximum angle of rotation and continued to swing to the left and right of position 0. The Lab view program was stopped after the swing arm had fallen back to position 0.

After each sample was fractured, an average inner diameter (i.e. average of maximum and minimum inner diameters) was measured for each specimen. Some of the marrow was removed to facilitate the measuring. The average inner diameter for the specimens was 5.70mm. The inner diameters ranged from 5.20mm to 6.56mm.

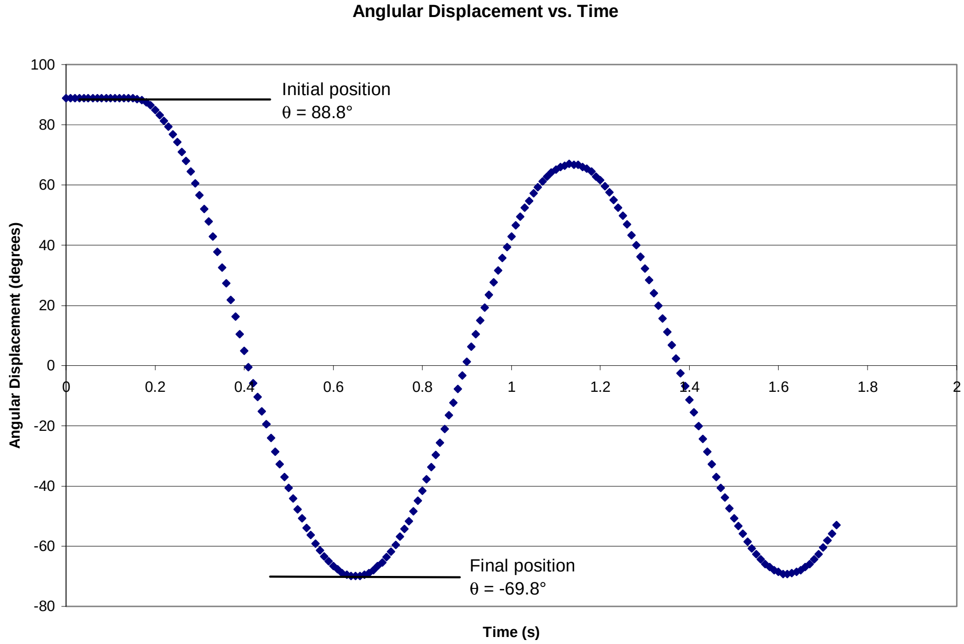
RESULTS:

The fractures of Specimens A, B, C, and D stayed along the plane of the swing arm's impact point (i.e., the plane in which the force was applied). The fractured surfaces of these specimens were more or less smooth and perpendicular to the neutral axis of the bone. The impact procedure for Specimen E, however, was not as optimal. A line of chicken tissue that ran across the surface of the bone axially was not removed in the cleaning process. The piece of tissue interacted with the swing arm, hooking the bone fragments momentarily to the pendulum after impact. This in turn created an unwanted force on the swing arm, thus giving inaccurate results.

To determine the breaking energy of chicken bone (E_{br}), the following formula was used where E_i is the initial potential energy of the system, E_f is the maximum potential energy of the swing arm after breaking, and E_{fr} is the frictional energy absorbed by the bearings of the swing arm:

$$E_{br} = E_i - E_f - E_{fr}$$

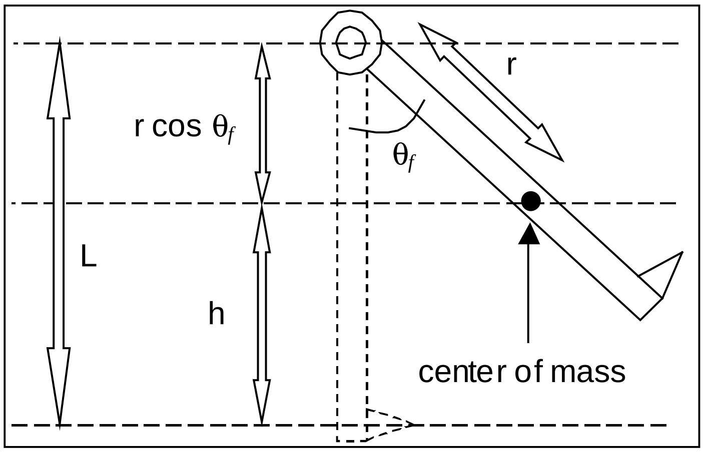
E_i and E_f are dependent on the angular positions (θ_i and θ_f) of the swing arm. This is determined by manipulating the voltage data that were recorded by the LabView™ Virtual Instrument program. Voltages varied as the swing arm rotated the potentiometer. These voltage readings were converted to angular displacements from the vertical axis by use of an angle versus voltage curve. This graph is shown in Figure 1 of the Appendix. The figure on the following page displays a representative angular displacement versus time graph for a chicken bone specimen. Figure 2 in the Appendix displays the curves for all the specimens. The curve initially remains constant. This represents the angle θ_i. As the pendulum is released, the angle decreases and reaches an ultimate minimum of angle θ_f.



The potential energies of the swing arm at the initial (E_i) and final (E_f) positions are calculated by the following, where m is the mass of the swing arm:

$$E = mgh$$

The height h (refer to the diagram to the right) is calculated by the following, where L is the length of the swing arm, r is the distance from the rotation axis to the swing arm's center of mass, and θ is the angular displacement from the vertical: $h = L - r\cos\theta$



E_f is the frictional energy absorbed as the swing arm traveled from θ_i to θ_f. This distance is approximated to be half a period of a pendulum's motion. Figure 3 displays a graph of the pendulum in free motion. To estimate E_f, the energy lost during one full period of motion was determined and divided by two.

The table below displays the calculated breaking energy and cross-sectional area of each specimen.

	Breaking Energy (Nm)	Cross-sectional Area (m^2)
Specimen A	0.411	2.84×10^{-5}
Specimen B	0.555	3.37×10^{-5}
Specimen C	0.631	3.56×10^{-5}
Specimen D	0.660	3.69×10^{-5}
Specimen E	*0.993*	2.85×10^{-5}

The average value of breaking energy was calculated to be:

$$E_{br} = 0.564 \pm 0.111 \text{ Nm} \quad (\%\text{error} = 20\%)$$

The energy value calculated for Specimen E was not incorporated into the average since experimentation errors occurred.

DISCUSSION:

One of the major objectives of this lab was to determine whether impact strength is a structural or material property. If impact strength were a material property then the values for the amount of energy absorbed by the bone in order to fracture it would be the same for all samples regardless of dimensions. The energy absorbed by the bone to fracture it is called the breaking energy. The breaking energy gives an indication of the impact strength. Impact strength is an inherent property of bone whether that property is material or structural. Thus, the angle at which the swing arm is positioned prior to release (θ_i) should not affect the breaking energy. The breaking energy is unaffected by the initial angle of positioning of the swing arm. With this in mind, we maintained a constant θ_i for all trials for the sake of consistency between trials, to reduce error that might be encountered when varying θ_i due to possible discrepancies in the voltage divider.

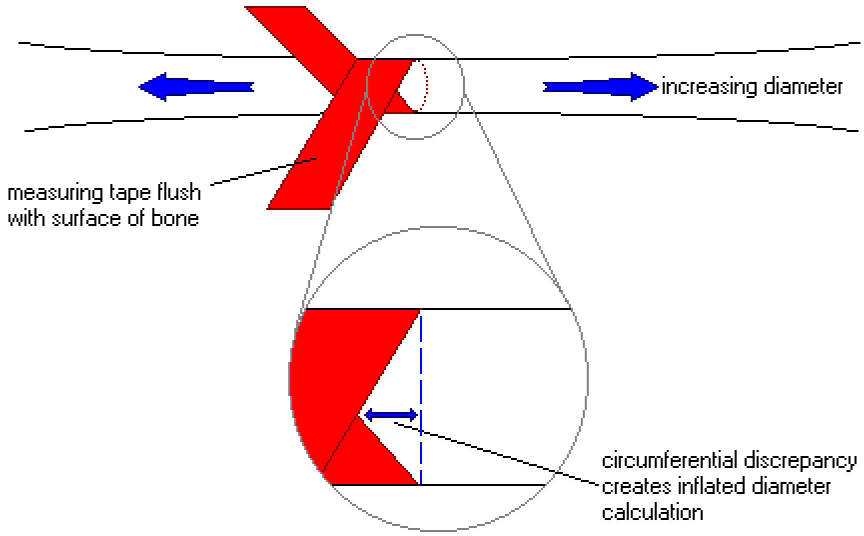
If the values of the breaking energy are different for each sample of varying dimension, this suggests that impact strength is a structural property. This is what our data shows. The average breaking energy for the samples was 0.569 N*m with a standard deviation of 0.11 and a 20% error. The breaking energies ranged from 0.411 N*m to 0.660 N*m.

It was observed that the values of the breaking energy increased with increased cross-sectional area. For example, the breaking energy for specimen A was 0.411 N*m; the specimen's cross-sectional area was $2.89\text{x}10^5\ m^2$. The breaking energy for specimen B was 0.555 N*m and its cross-sectional area was $3.34\text{x}10^5\ m^2$. Specimen B with a larger cross-sectional area possessed a greater breaking energy. This was the general trend among our samples: as cross-sectional area increased so did the breaking energy. This observation further supports our analysis that impact strength is a structural property.

Impact strength as a property of bone plays a vital role in the design of safety devices such as air bags. The purpose of air bags is to prevent the passengers of an automobile from sustaining severe injuries in the event of a collision. Air bags minimize the amount of force that the body will be subjected to during an accident. This buffering of the amount of force felt on the body prevents serious damage to the body. Thus, air bags act as a buffer between the impact of force felt by the vehicle and that felt by the passenger. Therefore, it is obvious that knowledge of the impact strength of human bones in the chest, neck and head, for example, would be critical in the design of air bags. Knowledge that breaking energy of bone is greater for a greater cross-sectional area also gives guidance of the requirement to maximize the amount of surface of impact contact. This information is essential in designing an air bag that will successfully buffer the passenger from the possibly fatal impact of a vehicular collision.

Perhaps the most evident error experienced within the lab was the absorption of energy in the pendulum due to friction within the bearings of the apparatus. Evidence of its existence is obvious due to the dampening effect observed in Fig. 3. Ideal equipment would yield no variation in angular displacement; that is identical values would exist for initial and return angles throughout the duration of the swing and, if left alone, would continue infinitely. Admittedly, a more accurate method of frictional calculation involves as angular determination of the pendulum swing based on a half of a period rather than a full period. Using this method a full swing of pendulum absent of any impact absorbing force would result in a marginally decreased angle of return. This angle is simply the difference between the maximum and minimum extrema, and is easily calculated by resolving the differences of maximum and minimum voltage within a single period. This, however, requires that our voltage meter be perfectly calibrated so that the voltage associated with an angle on the anterior side of the apparatus be absolutely consistent with that of the posterior side. Due to the fact that our apparatus did not meet these standards, the method employed throughout the experiment, although slightly less accurate than the method described above, was the only satisfactory one.

One of the less prevalent errors discovered in this lab was the method of calculation involving the radius of the bone, specifically the use of the ruling tape to measure the circumference. Due to the bone’s diminutive circumferential size, the thickness of the ruling tape significantly distorts the value of the bone’s circumference, thus rendering an inaccurate diameter. Furthermore, the thickness of the bones became greater at increasing distances from the intended breaking point, thus the width of the ruler hindered the readings by contacting the bone at a skew angle as demonstrated in the subsequent diagram.



Fortunately this error was realized while performing the lab and an alternative method of measurement was thus employed. Specifically, the caliper, accommodating an accuracy reading in increments of 0.05 mm, was employed at various angles around the intended breaking point, and thickness measurements were then averaged to achieve a more adequate diameter approximation for a circle.

The more predominant error related to circumferential discrepancy is that fact that the specimen at hand was not perfectly circular. Due to this intrinsic incongruity, no diameter reading can adequately satisfy exactitude, and internal stresses upon the bone are slightly varied, thus also fluctuating the precision of the energy absorption due to impact. A computational modification acting to diminish this error is to treat the cross-sectional area of the specimen as an ellipse. Thus the calculations would portray a more accurate representation of the structural properties of the bone specifically related to its impact strength.

The fact that the specimens in question did not break exactly in half, but rather on slightly skewed courses indicates yet another erroneous occurrence. This deviance from expectation is justified by considering the composition of the specimen itself. It is inherently obvious that due to its biological nature, bone is not a perfectly homogeneous material, but is composed with limited consistency. This heterogeneous composition facilitates varied stresses over given areas, thus causing some portions of the specimen to fracture under a given load more readily than others. Thus a bone accommodating a greater percentage of relatively brittle substance will fracture at a lesser load and thus withstand a lesser impact force than a specimen with a greater percentage of a more rigid material.

Related to the heterogeneous consistency of different portions are the molecular properties of the specimen. Proteins within the cellular matrix of bone directly relate to its rigidity. Thus the absence of these proteins due to malnutrition or simple degradation over time may have a profound effect on the specimen's material properties. For instance, a cluster of cells accommodating few microtubules yield more easily to compression and will thus buckle under smaller loads. This action not only compromises the material and structural integrity of the immediate cluster but also neighboring areas, as they must support relatively larger compressive forces per given load.

To limit the effects of such discrepancies between specimens, the bones should be stripped of surrounding tissue days in advance of the lab and reside in identical environmental conditions until experimental use.

Aside from the legitimate modifications previously stated to facilitate a decrease in the error experienced throughout the lab, an increase in the voltage values collected per second could improve the exact value of the upper and lower bounds of the range of voltage. Such a modification will allow for the collection of a greater amount of data, thus more points will exist, creating a more accurate graphical representation of the data and amplifying the accuracy of the upper and lower voltages per period. This amplified accuracy would directly improve the precision of the angle of return and thus the value accrued for the impact strength of bone.

CONCLUSION:

The main objective for this experiment of determining the breaking energies of chicken bones was successful. Most of the bones broke on a smooth fracture upon impact, leading to a clear and consistent data that indicates that breaking energy of chicken bones range from 0.411 N*m to 0.660 N*m, with larger values when impact was upon a larger cross-sectional area. This is exactly what we expected, as we hypothesized that impact strength was a structural property, not a material one. A relatively large percentage error of 20 also serves to indicate that the breaking energy was not supposed to be the same value across the samples. The experiment could be further improved with better ways of calibrating the setup and relating the output voltage to the angles more accurately.

Success in determining impact strength of bones is important for many biomedical applications. With such knowledge, manufacturing of such safety devices such as seat belts and air bags can reduce the effects of impact, minimizing the energy to what would be the safety level to prevent bone fracture. Additionally, knowledge of the relationship of breaking energy to the structure of bone also allows the manufacturing of the safety device that would take advantage of the structural property in offsetting bone fracture. Design of seat belts and air bags, for example, must distribute the impact upon larger cross sectional area of bone. Thus studying of impact collision on bones allows the fabrication of safety devices that would prevent painful and difficult-to-heal incidences of bone fracture.

APPENDIX:

Figure 1: Angle vs. Voltage

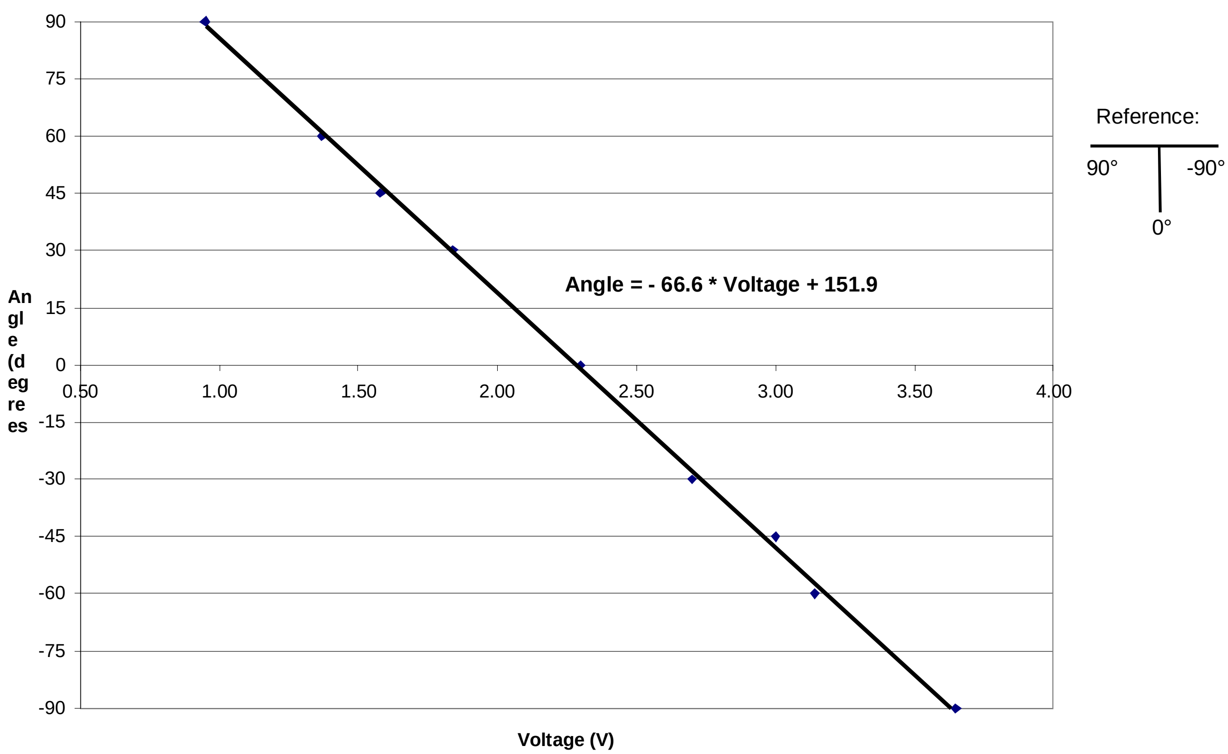


Figure 2: Anglular Displacement vs. Time

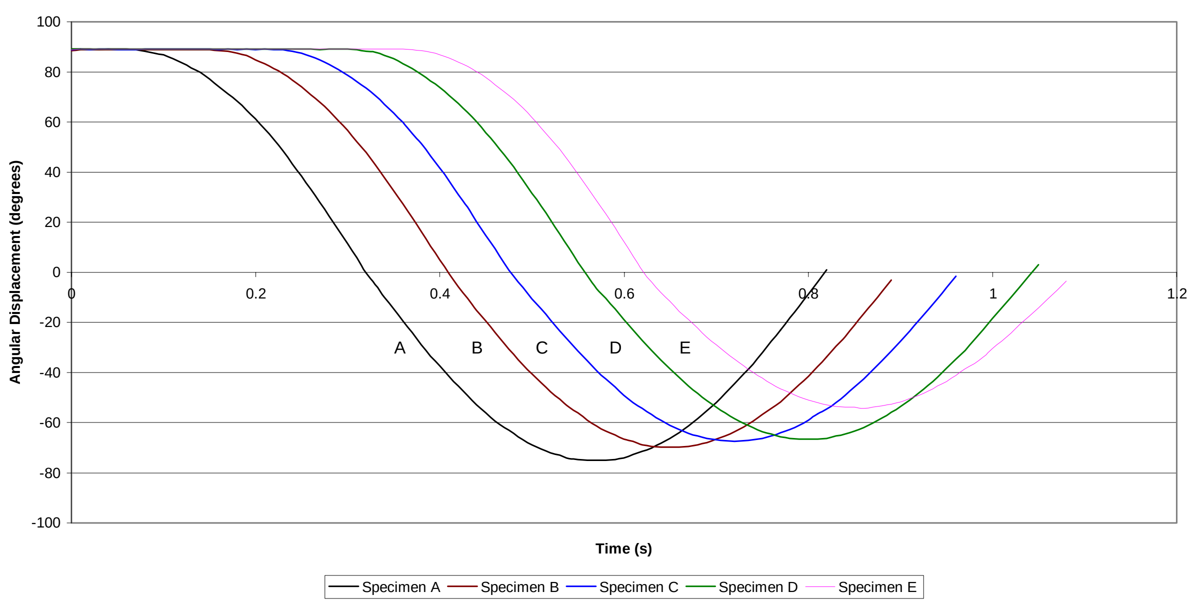


Figure 3: Free-Swinging Pendulum