BE 209 – Group BEW6
Jocelyn Poruthur, Justin Tannir
Alice Wu, & Jeffrey Wu
October 15, 1999

# Three Point Bending of Chicken Bones

## INTRODUCTION:

In this lab, we applied the method of three-point bending to determine some quantitative mechanical properties of chicken bone. Specifically, we attempt to find the value of *stiffness*, which is force over displacement; *yield force*, which is the force at which the bone goes through irreversible deformation, and the *breaking force*, which is the force at which the bone breaks. Coupled with the knowledge about the dimension of the bone, we can derive the values of *elastic modulus*, which is the ratio of stress over strain on a linear portion of the stress-strain curve; *yield stress*, or the stress at which point the bone stretches irreversibly; and *breaking stress*, which is the stress at which the bone cracks. In addition, we wish to observe the location and appearance of the bone fracture.

We expect to see a fracture of the bone at the location where force was applied. Also, because the bone is a relatively brittle material, we expect to see that there will be very little elongation of the specimens before it breaks. Thus, the value of the yield force will be very close to the breaking force, and the value of yield stress will also be similar in magnitude to the breaking stress. We also expect fairly large value of stiffness and elastic modulus. We also expect to see the bones display subtle evidence of linear plasticity, as attempts are made in the lab to keep the bone wet. Thus the bones will exhibit more ductile characteristic than if it had been dry. Furthermore, we expect to see the same value of elastic modulus, yield stress, and breaking force for all bone chicken bones because they are theoretically material properties. On the other hand, stiffness, yield force, and breaking force are structural properties and should vary from sample to sample.

## METHODS & MATERIALS:

By means of a scalpel, the meat and other tissue were cut off of the five raw chicken legs that were provided. After the bones were removed of meat and tissue, they were placed on paper towels immersed in saline solution to prevent drying. The dimensions of each bone with respect to diameter were taken. Since the bones are not perfectly cylindrical, an average outer diameter was measured. The outer diameter of the chicken bone was taken approximately at the midpoint of the bone, which was subsequently marked. A caliper was used to take the diameter of the bone at the marked position. This marked position would be where the support point of the loading frame would be directed. Two diameters were taken at the marked site: a maximum and a minimum diameter. The average of these two measurements was used as the outer diameter of the bone. The average outer bone diameter for the five samples was 15.94mm. The outer diameters ranged from 15.5mm to 16.06mm. The lengths of the samples were taken to be the distance between the two support points of the loading frames. This length was constant for each sample and was measured a 50.40mm.

The Instron Model 4444 table-top mechanical testing machine was used to apply compressive stresses on the bones. Before the samples were tested, a calibration curve was constructed. Standard metric weights were massed and then hung from a hook attached to the force transducer of the Instron machine. Figure 1 in the appendix displays this calibration curve.

Instructions provided for calibrating and balancing the Instron machine prior to each trial were used, that is, the load and gauge length were set to zero before each trial was performed.

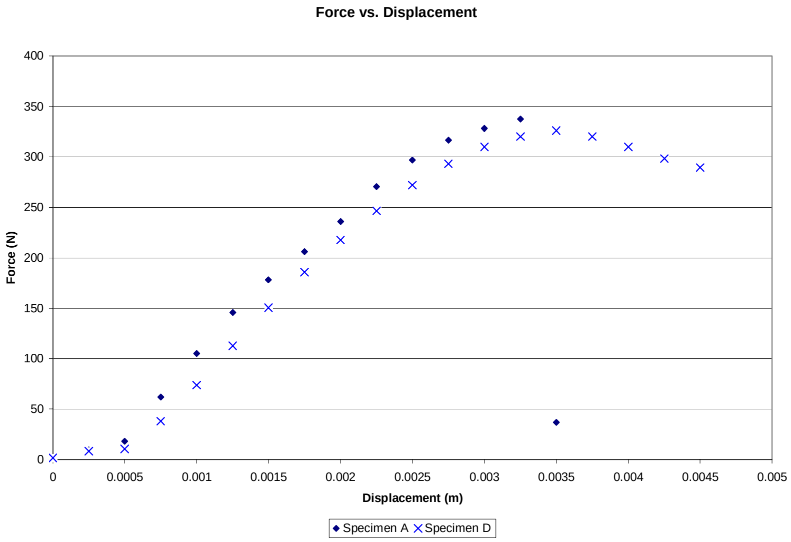
Trials were run at a crosshead speed of 100mm/min and a data collection speed of 100 data points per second. The samples were situated on the support points of the support frame so that the marked line on the bones (indicating the approximate midpoint and the cross-section whose diameter was measured) was in the direct line of the support point of the loading frame. Once a sample was positioned properly on the loading frame, the Instron machine was started. The machine compressed each sample until the breaking point at which time the machine automatically stopped – this was the result of a programmed safety-feature. After a sample broke an average inner diameter was measured by means of a caliper at the cross-section of the breakage. The average inner bone diameter for the samples was 10.57mm. The inner diameters ranged from 9.65mm to 10.99mm.

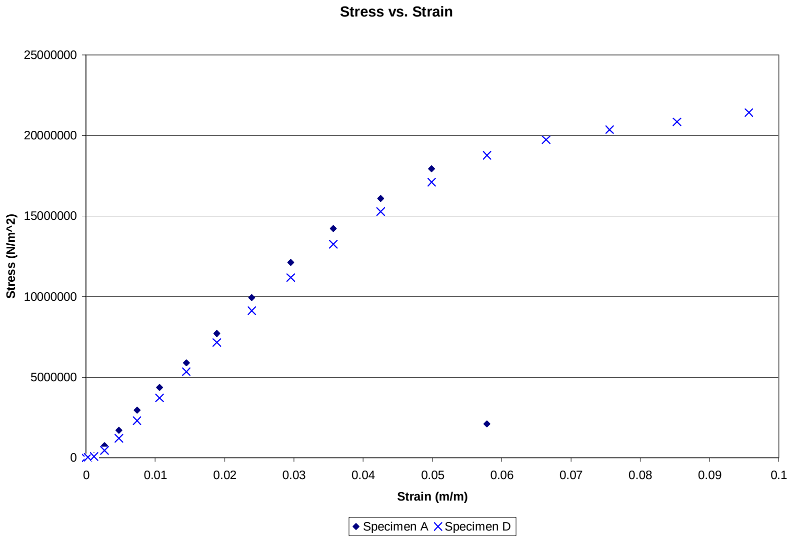
## RESULTS:

As the support point of the loading frame applied a force to the chicken bones, the neutral axis of the bone started to bend into a parabolic shape. With a high enough load is applied, the bottom portion of the bone was observed to break first. The crack traveled upward until the bone fractured in two pieces or until the Instron™ machine ceased loading for safety purposes. The two portions of the bone were connected by bone marrow.

The fractures of Specimens A, B, C, and D stayed along the plane of the loading frame's support joint (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 loading process for Specimen E, however, was not as ideal. The ends of this bone bent upwards more so than the other specimens. The two ends came into contact with the loading frame, thus creating a force opposing the downward load. The initial data collected is still be used for calculations.

Figures 2 and 3 from the Appendix displays the force verses displacement and stress versus strain graphs for Specimens A, B, C, and D. Figures 4 and 5 shows these graphs for Specimen E. Sample graphs of these types are show below for reference. From the force versus displacement graph, the stiffness constant (k) is determined by taking the slope of the linear portion of the graph. Yield force is determined by observing the point where strain increases significantly with no considerable increase in stress. The breaking force is at the point where there is maximum stress before breakage. The stress versus strain graph as the one below is needed. From this graph, Young’s modulus, yield stress, and breaking stress can be determined.


Force vs. Displacement


Stress vs. Strain

The table below summarized the results of this experiment:

| *All results in SI units* | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Specimen** | **Area** | **k** | **Yield Force** | **Breaking force** | **E** | **Yield stress** | **Breaking stress** |
| **A** | 1.04E-04 | 1.27E+05 | 3.28E+02 | 3.38E+02 | 4.11E+08 | 1.61E+07 | 1.79E+07 |
| ***B*** | 1.13E-04 | 1.45E+05 | 3.64E+02 | 3.50E+02 | 4.34E+08 | 2.05E+07 | 2.37E+07 |
| ***C*** | 1.14E-04 | 1.30E+05 | 2.37E+02 | 2.32E+02 | 3.63E+08 | 9.38E+06 | 1.09E+07 |
| ***D*** | 1.16E-04 | 1.19E+05 | 3.20E+02 | 2.89E+02 | 3.77E+08 | 1.97E+07 | 2.14E+07 |
| ***E*** | 1.28E-04 | 1.60E+05 | / / / | / / / | 3.96E+08 | / / / | / / / |

Since stiffness, yield force, and breaking force are structural properties that are dependent on the material and geometric properties. All the specimens varied in cross-sectional areas; therefore, no correlations could be made among the different values. Young's modulus is a material property that should be constant for all samples of chicken bones. The average value for E is:

$$E_{chicken\ bone} = 3.96 \pm 0.28 \times 10^{8}\ N/m^{2} \quad (\%error = 7.03\%)$$

There does not seem to be any correlation for the different yield and breaking stresses, so no average value could be calculated.

## DISCUSSION:

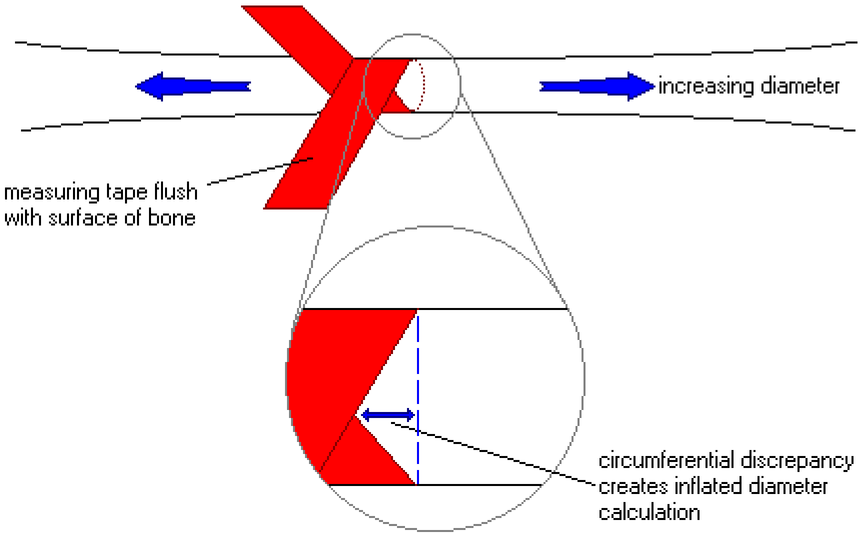
The stress-strain diagrams constructed for each sample indicate the material properties of the samples. The slope of the linear portion of the stress-strain diagram is equal to the modulus of elasticity of the material. An analysis of our data shows that the bones demonstrated linear plasticity. From the stress-strain diagram, it is evident that the graph begins as a linear plot and then begins to curve until the sample breaks. Such a plot indicates the linear plasticity of a material. The linear portion of the curve represents the range for which the stress and strain are proportional. Once the samples reach the proportional limit, the graph begins to curve indicating that the stress incurred by the sample is no longer directly proportional to the strain. According to Riley's Statics and Mechanics of Materials, the proportional limit is the maximum stress for which stress and strain are proportional. The proportional limit is quantified by the yield stress. The yield stress is defined as the stress at which there is an appreciable increase in strain with no increase in stress; if straining is continued the stress will increase again. The application of the yield stress is presented by the curving of the stress-strain diagram. The curved portion represents the plasticity of the material. Once the sample has reached the point where it undergoes plastic deformation, the strain resulting from loading will not disappear upon load removal. The curve ends when the breaking stress of the material is reached.

Linear plasticity is a property of wet bone. Dry bone, on the other hand, is brittle and a stress vs. strain diagram should produce a linear graph that stops at the breaking point. A dry bone will reach its breaking point faster than wet bone under identical experimental conditions. The moisture of the wet bone allows it to demonstrate plasticity. This is a property of bone that adds to its strength. Still, too much moisture can present error when attempting to produce breakage of bones. We encountered such a problem in our trials. When testing specimen E, the sample did not break at the average force that broke the other samples. Instead, the bone began to bend and crack and the internal fluids, such as blood, leaked from within the sample. At that point the Instron machine had to be manually stopped because it did not sense breakage. The machine was programmed so as to stop force application upon sample breakage. Consequently, the data obtained for specimen E was not included in the analysis of the samples since the results were inconclusive.

The observation of the importance of the moisture of the bone is significant in the development of artificial bone that will be most compatible to the body chemistry and daily routine of the average person when chicken bone is used as a model of human bone. If the bone is too moist it will be more susceptible to fracture than to breakage, which is often deemed more favorable in terms of recovery. If the bone is too dry, it will be more susceptible to breakage during routine daily activities such as walking and running.

The force vs. displacement graphs demonstrate structural properties, that is, dependence on geometry as well as material properties. The slope of the force vs. displacement graph is equal to the stiffness, *k*, of the sample. Our trials also provided information about structural properties of chicken bone, such as stiffness, yield force and breaking force. These values varied from sample to sample since they exhibit dependence upon the geometry of the samples. The knowledge of the structural properties of a particular sample of material is vital in construction of bone replacements. For instance, the bones found in the foot are not geometrically identical to those in the arm. Bones in the foot are smaller, with shorter diameters and lengths and many of these smaller bones make up the construction of the foot. Such a system of bones would not be as efficient in the arm.

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 modulus of elasticity value.  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 material properties of the bone, specifically stress and Young's Modulus.

The fact that the specimens in question did not break exactly in half, but rather on 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.

Once fractures are formed in the material, the specimen's ability to plastically deform increases (due to bowing of the sides of the specimen) at the expense of diminished stiffness.

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 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, a decrease in crosshead speed of the Instron™ could significantly improve Young's Modulus specifically. Although this amendment plays no role in preventing premature fraction, a slower crosshead speed 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 variances due to partial fracture. These amplified variances would allow the data analysis specialists to identify the point where partial fracture is initially evident. By identifying initial fracture, the specialists can isolate their relevant data to points before this incident, thus producing a more accurate slope and, in turn, modulus of elasticity.

## CONCLUSION:

The main objectives for this experiment of determining the stiffness, yield force/stress, breaking force/stress, and Young's modulus for chicken bone were successful. Breakage of the bone was a smooth fracture along the plane of the force, as expected. This provided consistent data, as exemplified by the low percent error (7.03%) for the average Young's modulus. The yield stresses and breaking stresses were hypothesized to be material properties. The results, however, showed varied values for these stresses. A possible source of error would be the approximated radius that was made for the non-circular bone.

Success in examining the material and structural properties of chicken bone is important for many biomedical applications. Method used in determining the attributes of chicken bone can be directly applied to human bones so that replacement of the bone by other synthetic materials is possible. Coupled with the knowledge of the daily forces exerted on certain bone parts, it is possible to manufacture an artificial bone that can safely replace the real bone with minimal chances of failure.

# APPENDIX:

**Figure 1: Electronic Balance Mass vs. Instron Mass**

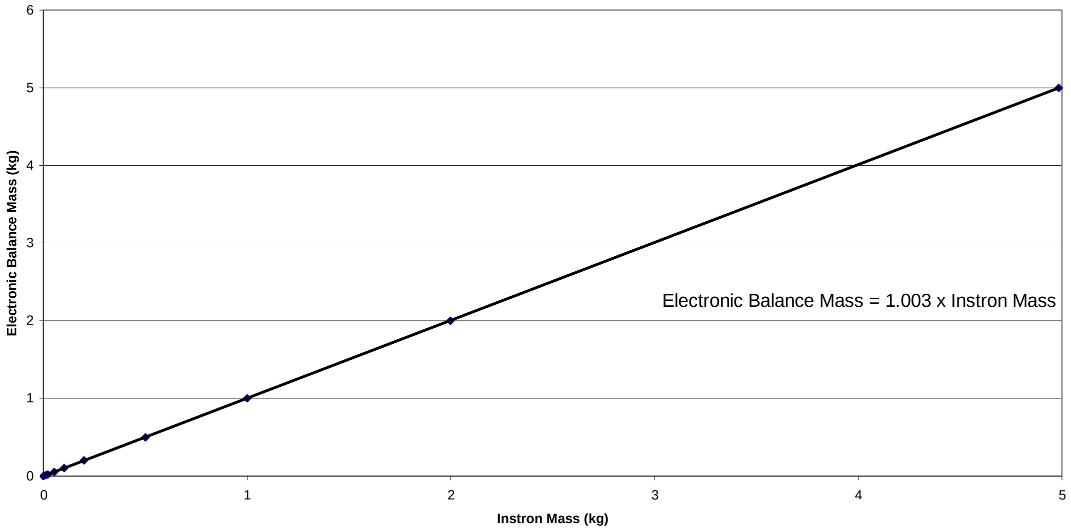


**Figure 2: Force vs. Displacement**

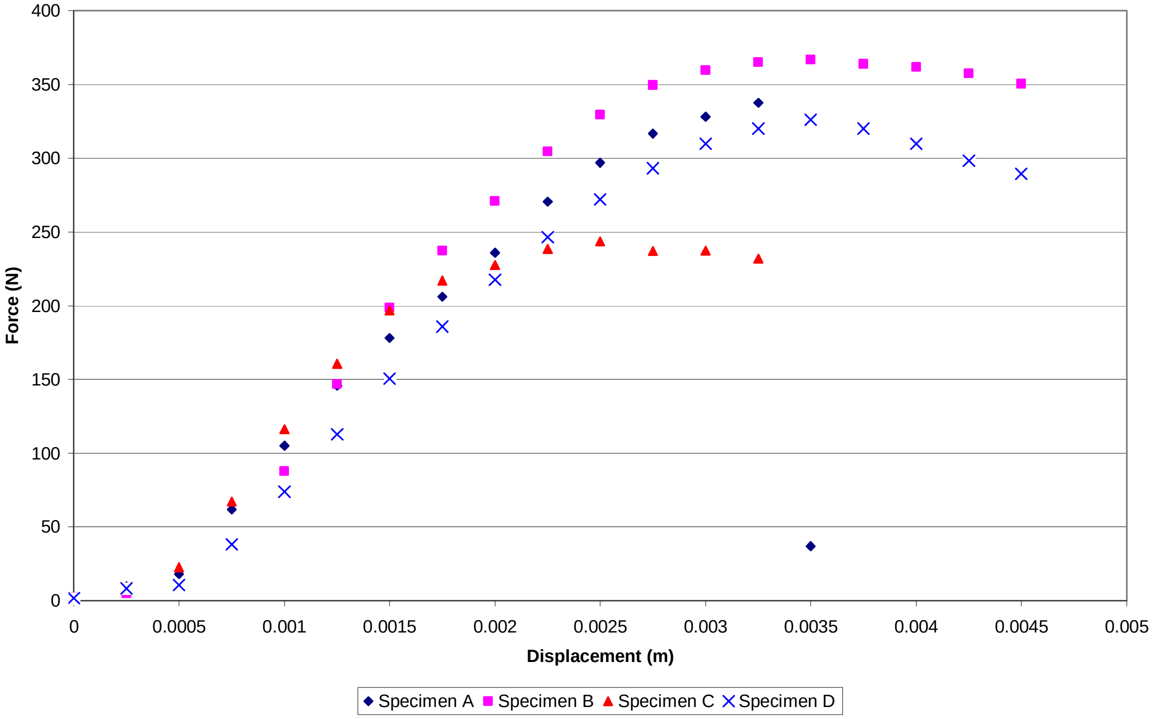


Figure 3: Stress vs. Strain

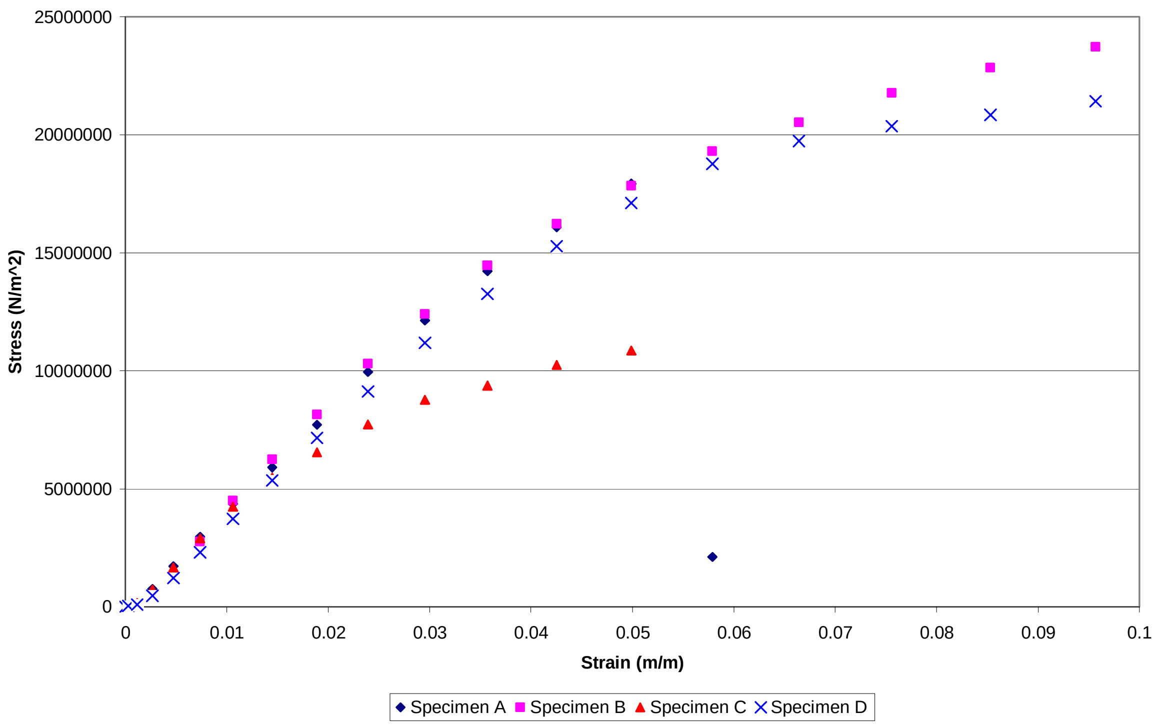


Figure 4: Force vs. Displacement

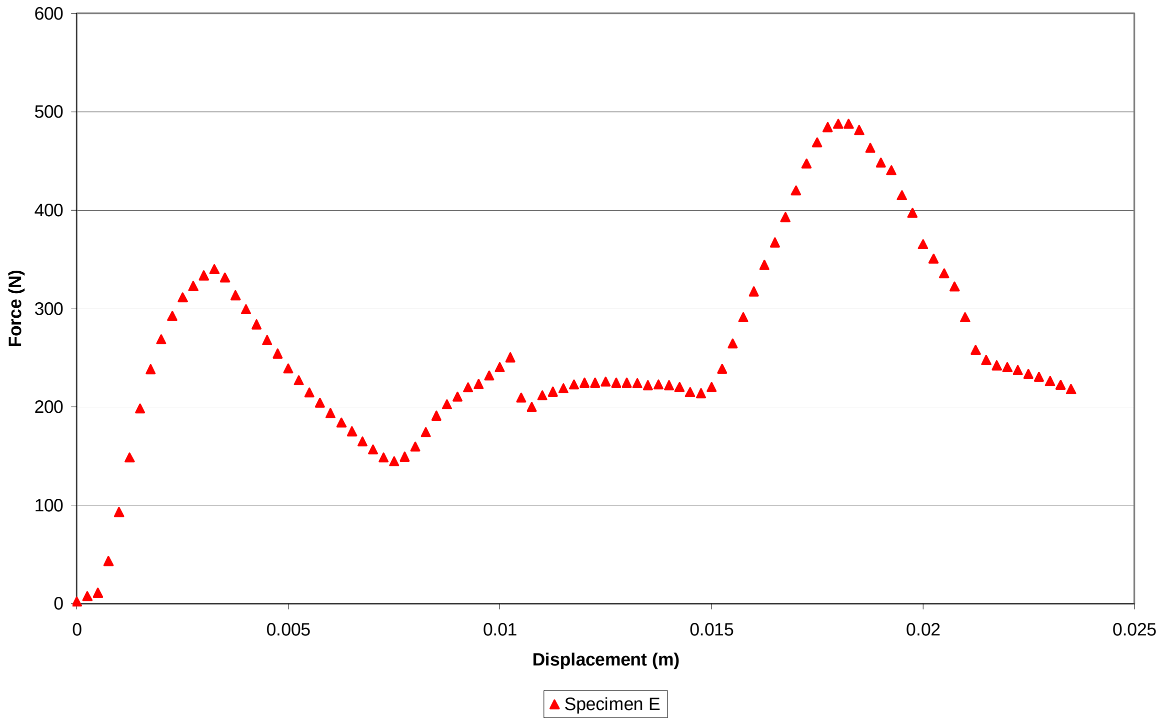


**Figure 5: Stress vs. Strain**