STRENGTH OF MATERIALS

Minster

ABSTRACT

Bone is the primary structure of the human body to protect internal organs. Thus, it is important to biomechanical engineers to understand the behavior of bones for implants in orthopedics field. This lab is designed to understand mechanical behaviors of various materials and under different settings. The mechanical response of rubber and bone were tested of stress. With the results, students investigate potential complexities and sources of error. Also students will evaluate data with stress vs. strain, load vs. displacement graphs of three different tests with wet and dry chicken bones. The settings are compression test, 3 and 4 point bending and Therabands under tensile and relaxation stress.

INTRODUCTION

Bone is the primary structural element of the human body. It serves to protect vital internal organs and provides a framework that allows the skeletal motions that are necessary for survival. Thus, this lab is designed to lean how biomedical engineers can decide whether patients need implants or not. The purpose of testing strength of materials is to understand tensile stress, bending, compression, and other various main mechanical properties. Biomedical engineers need to apply materials for proper treatments and to select for the best efficiency.

For this lab, Therabands and wet & dry chicken bones were used in three different tests to quantify mechanical responses and investigate potential complexities and sources of error. A materials testing machine was used to measure tensile strength, yield strength, plastic and elastic deformation, Young's modulus, and relaxation. The first test used Therabands in a tensile stress test and a relaxation stress test. The second test used wet and dry chicken bones in a compression stress test. The third test used wet and dry chicken bones in 3 and 4 point bending tests. The Therabands used in this lab had different resistance levels such as yellow being the weakest, green is medium, and blue is the strongest. These Therabands are used mostly in physical therapy to improve muscular endurance and strength, range of motion and flexibility. The chicken bones used in this lab were either wet or dry. The wet bones represented young, typical bones and were fresh from a chicken and stored in a moist environment. The dry bones represented old, brittle bones and were cooked in an over for an hour about 325 Celsius degrees. According to stress vs. strain graph, the proportional limit, elastic limit, yield point, ultimate strength and rupture strength were found. The proportional limit is the point on the graph where the curve becomes non linear. The elastic limit is the greatest stress which the material is capable of sustaining without permanent deformation occurring. The yield point is the point on the curve where permanent deformation of the specimen begins to take place. The ultimate strength is the highest point on the stress vs. strain graph which is the maximum resistance to fracture. The rupture strength is the stress at which the specimen fractures. Isotropic materials have the same material properties in every direction such as cardiac muscle. Anisotropic materials have material properties that are direction dependent such as bones. Orthotropic materials have different properties in three orthogonal planes such as tendons. In terms of mechanical response, biological engineering materials perform like composite materials and are stronger in compression compared to traditional engineering materials which are made of individual components such as plastics, ceramics or metals.

METHOD

There are main three parts of this lab. The first one is testing strength of rubber, the second one is testing strength of chicken bones, and the third one is testing 3-point and 4-point bending.

1. Rubber

Students picked a blue theraband from yellow, green, and blue. The resting length, width and thickness of the theraband were carefully measured with digital caliper. Then calculate the cross sectional area. Tightly mount the specimen in the MTS test machine (5kN load cell). Now, the length of the initial length of the specimen was measured which is the distance between the MTS clippers. After students loaded the MTS TestWorks program, the tensile test began. The initial crosshead speed was 2 in/min. The fine tune dial was on the MTS to remove slack from the theraband sample. To prevent potential over loading of the load cell, set the mechanical safety stop to constrain the cross head from going beyond the test area. When students press the green run button, the MTS pulls the specimen with 2in/min speed until it reaches about the specimen reaches a stretch ratio of about 1.2 (20%). When the stretch ratio of the specimen is about 20%, stop the machine, measure the cross section. Save the data and then return. Then the spped of crosshead is changes to 5 in/min. Perfrom the same tensile stress testing but for this time, let it go until the specimen breaks. For emergency, when the force approaches 3kN or 700lb, press the stop button.

Students picked a yellow theraband for second specimen. Students performed same procedure as the first specimen (blue theraband) until mount in the MTS test machine. Students let the theraband were stretched for 30seconds and pausing for 2 minutes. Then they continued the experiment until failure. This is the relaxation test that followed by tensile load to failure testing.

2. Bones

Students picked three wet chicken bones and three dry chicken bones. The first experiment used only one dry bone and one wet bone. Students inserted the upper and lower bone holders into the MTS test machine. Then they performed bone compression experiment with MTS TestWorks program with dry bone first. The crosshead speed was 0.5 in/min. Measure and record the specimen diameter in two directions. The mean value is used for calculating the approximate cross sectional area of the specimen, assuming that the cross section is circular. Then carefully mounted the specimen into the holders and positioned in the MTS test machine tightly. Measure and record the initial length of the specimen, the distances between the cap bases. Initiate the load to failure test and the experiment began with pressing green run button.

After performed the testing with dry bone, students tested same test with a wet chicken bone. They are going to follow the same step as the dry bone.

Finally, clean up the holders and machines.

3. 3-point and 4-point bending

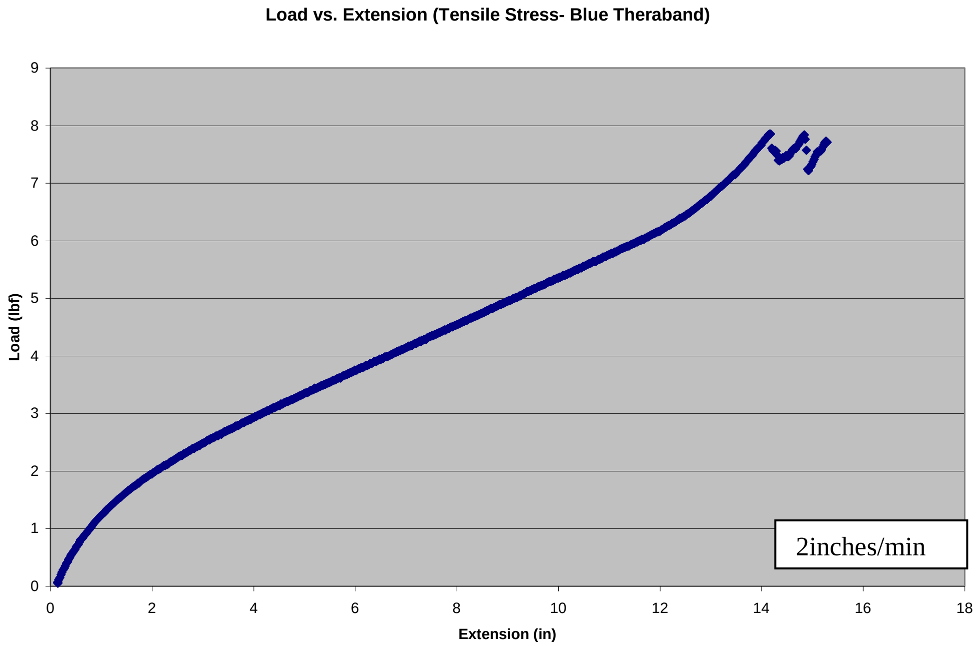
Students carefully inserted the bending apparatus into the MTS test machine for three-point bending first. Then place a dry bone and try to center the top load with respect to the bottom supports. If it is necessary, then adjust the crosshead position. To initiate bending, pressing the green run button. For emergency, when load cell is approaching 4kN, then press stop button. However, continue loading until failure is observed. After the experiment, clean the holders, and machine for the next experiment with a wet bone.

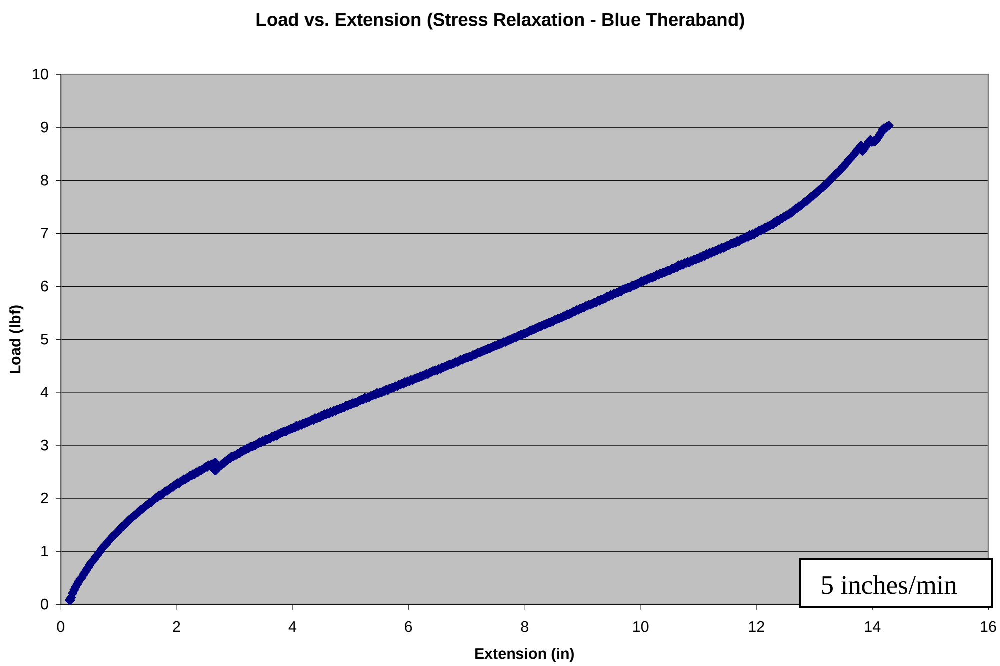
Students carefully inserted the bending apparatus into the MTS test machine for three-point bending with a wet bone. Students followed same step as the dry bone.

Students did the experiment with 4-point bending as well when time permits. Students carefully inserted the bending apparatus into the MTS test machine for four-point bending. Then place a dry bone and try to center the top load with respect to the bottom support. It is more stable than the 3-point bending. Rest of steps are same as the 3 point bending experiment.

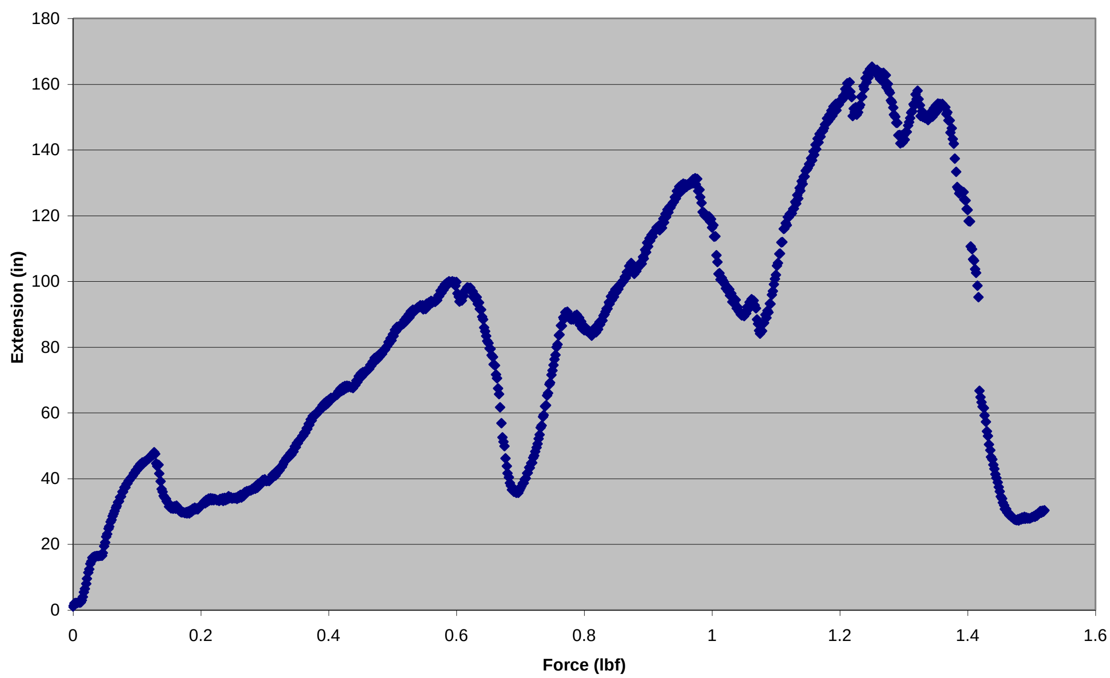
RESULTS

A. Load vs. Extension Curves for Tensile (Theraband), Relaxation (Theraband) and Compression (Bone) Load-to-Failure tests

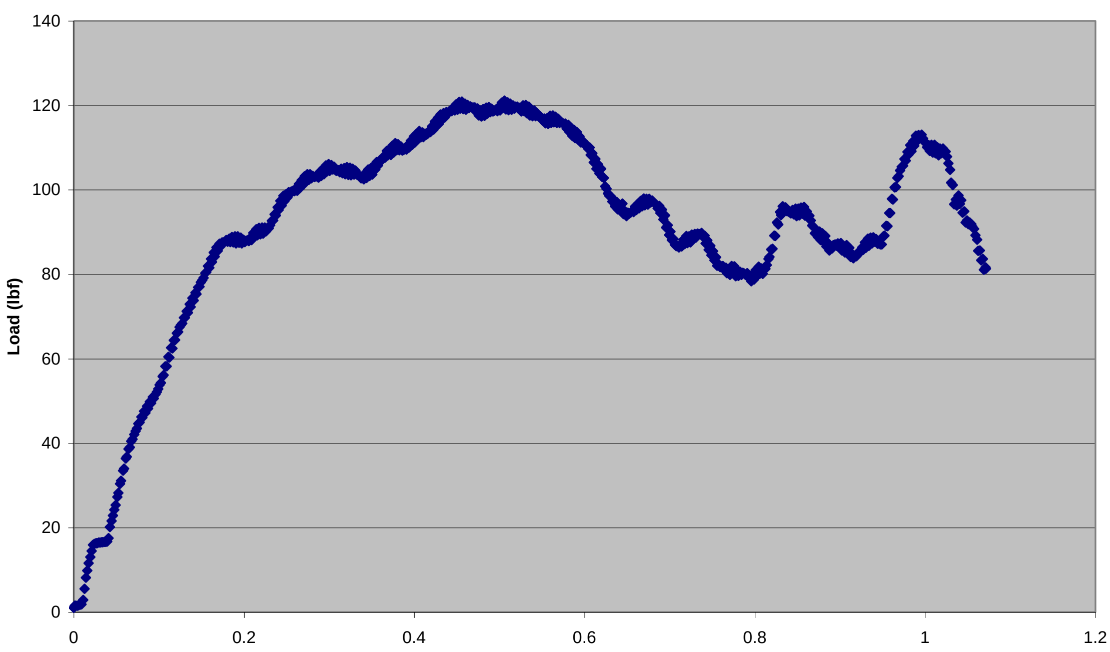




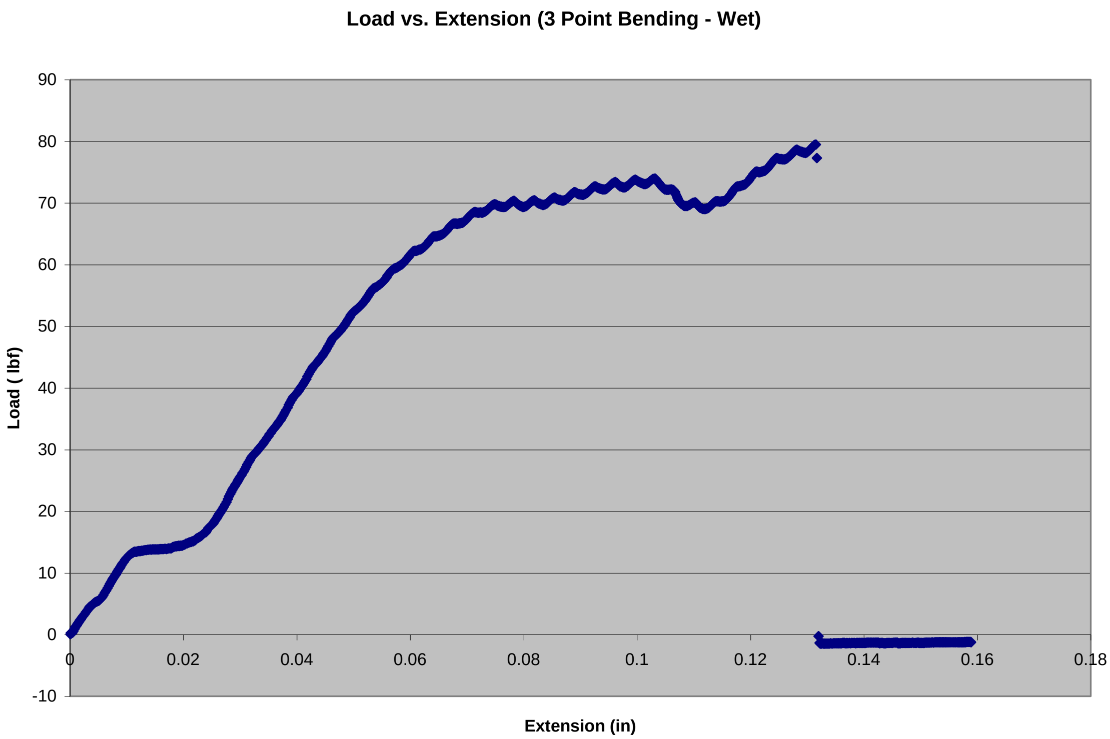
Load vs. Extension (Compression - Wet)

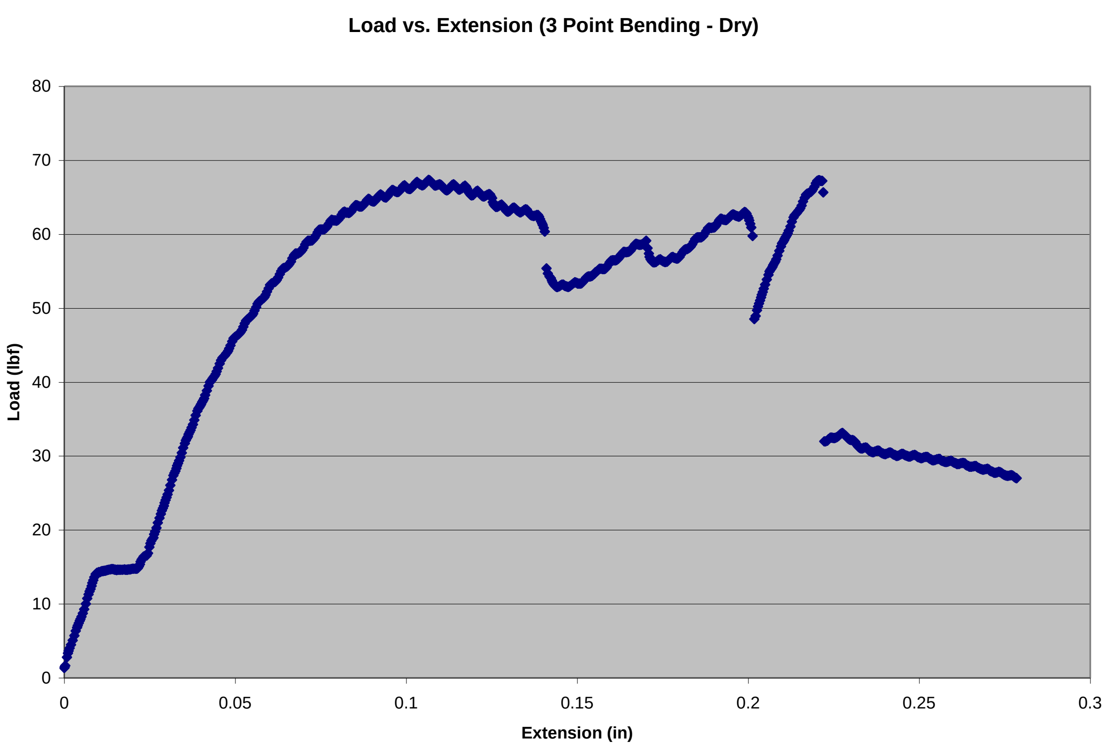


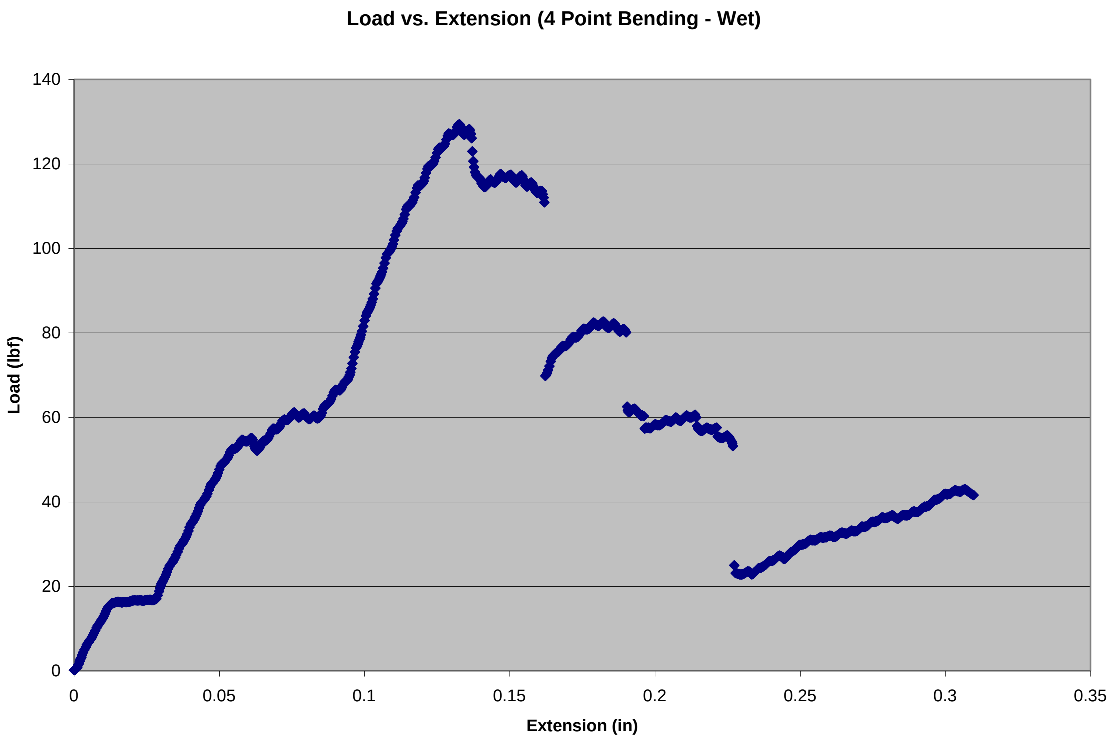
Load vs. Extension (Compression - Dry)

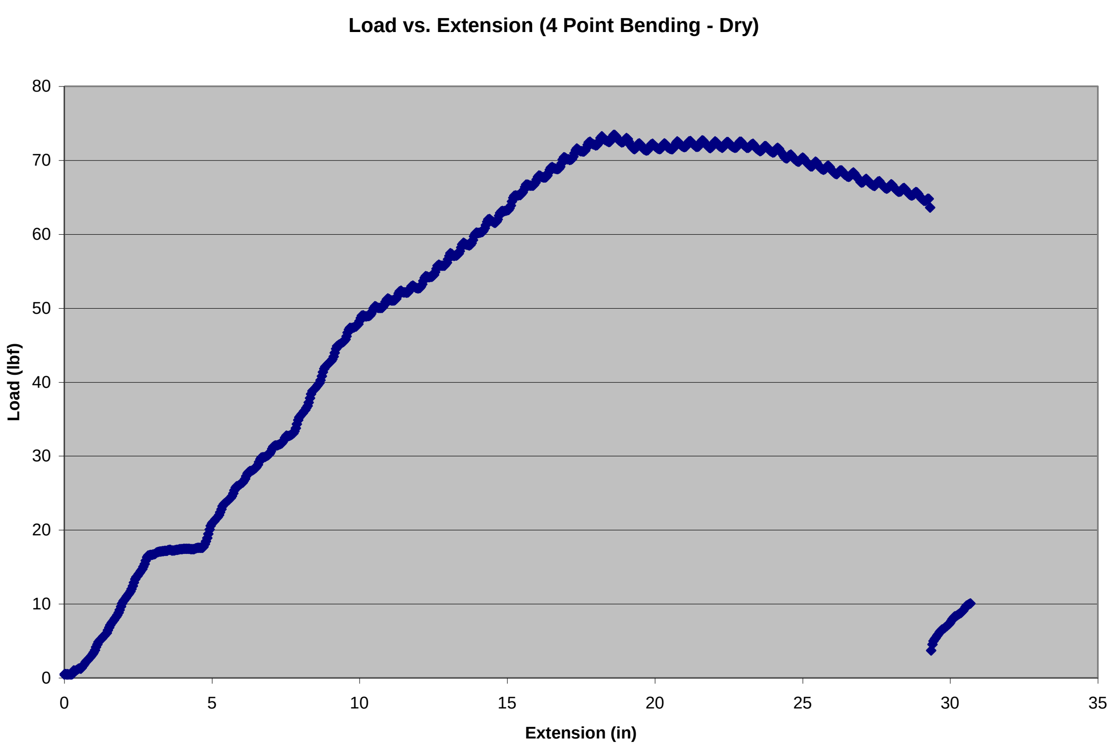


Displacement (in)

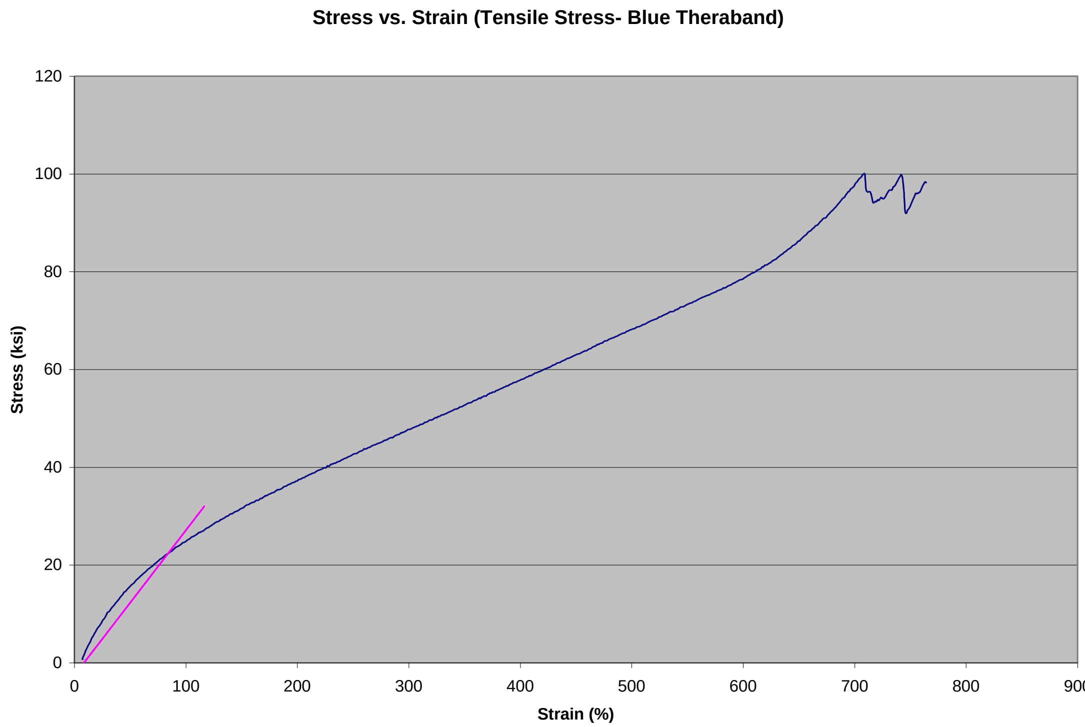

Load vs. Extension (3 Point Bending - Wet)
Load (lbf)
Extension (in)
90
80
70
60
50
40
30
20
10
0
-10
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18

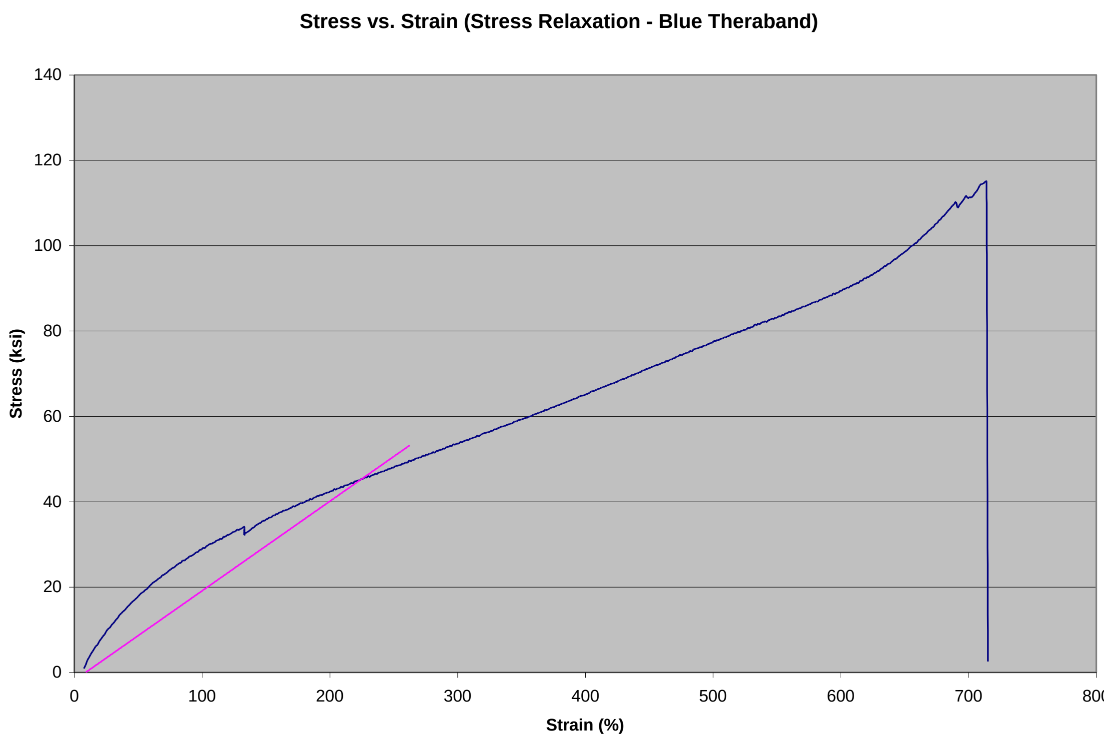

Load vs. Extension (3 Point Bending - Dry)
Load (lbf)
Extension (in)
80
70
60
50
40
30
20
10
0
0
0.05
0.1
0.15
0.2
0.25
0.3

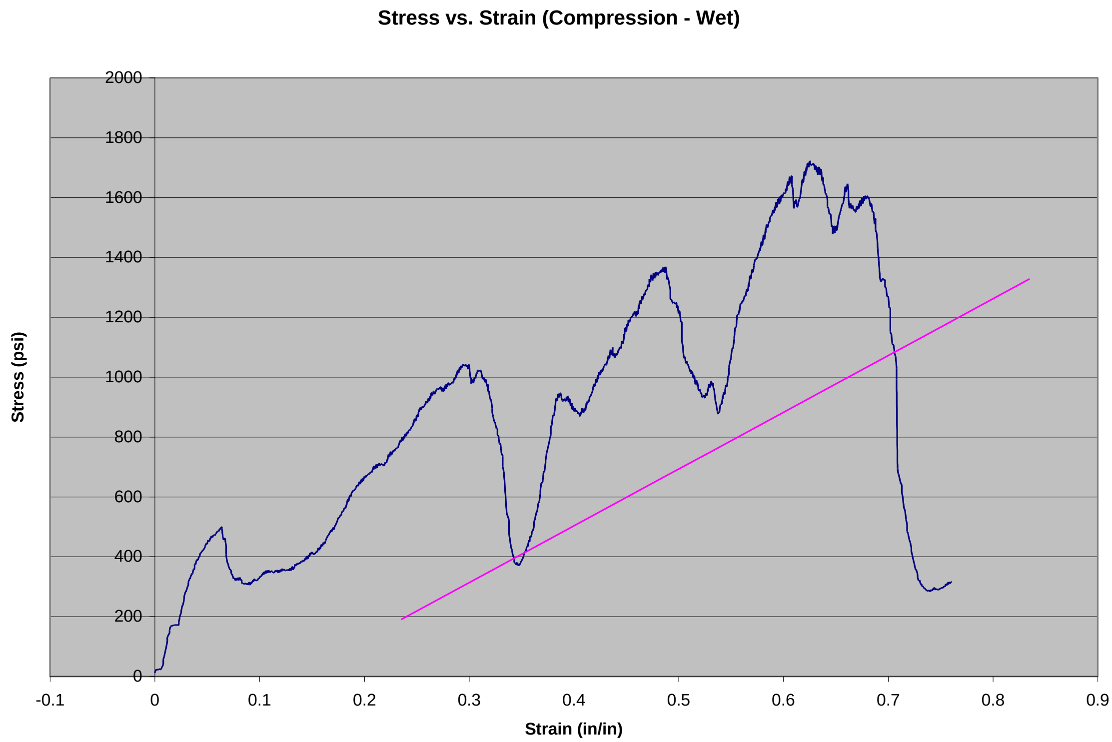

Load vs. Extension (4 Point Bending - Wet)
Load (lbf)
Extension (in)
0
20
40
60
80
100
120
140
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35

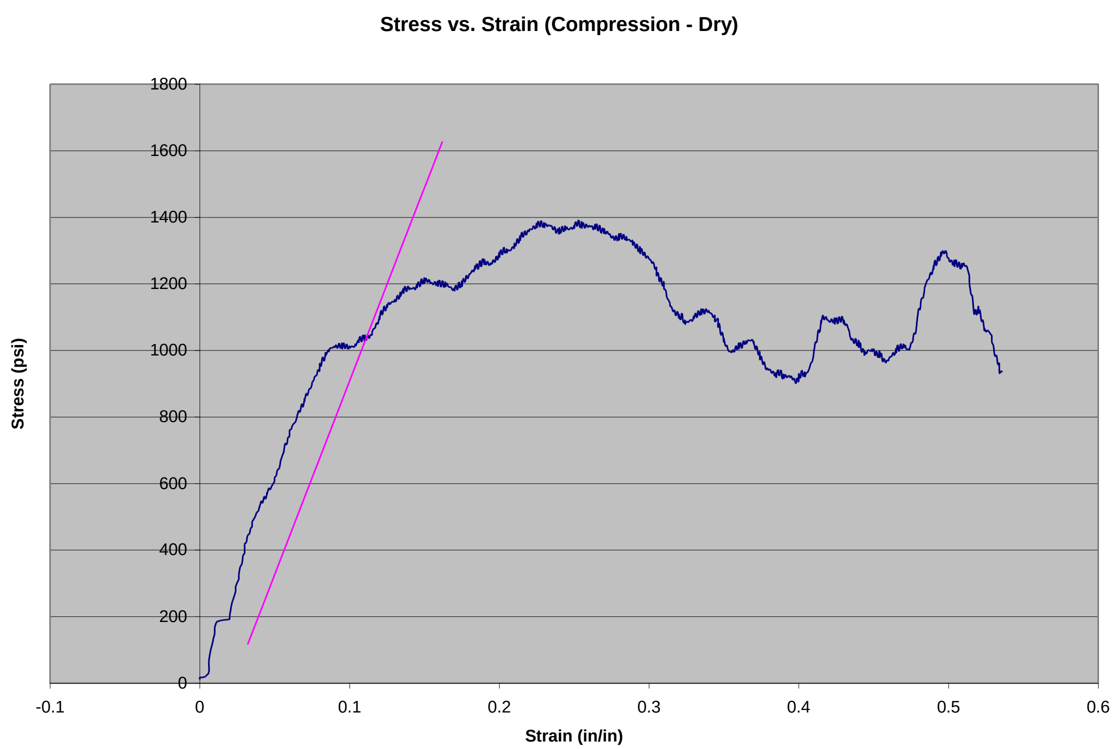

Load vs. Extension (4 Point Bending - Dry)
Load (lbf)
Extension (in)
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30
35

B. Stress – Strain Curves for Tensile (Theraband), Relaxation (Theraband) and Compression (Bone) Load-to-Failure Tests






Stress vs. Strain (Compression - Wet)
Stress (psi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Strain (in/in)


Stress vs. Strain (Compression - Dry)
Stress (psi)
1800
1600
1400
1200
1000
800
600
400
200
0
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
Strain (in/in)

C. Measurements, Proportional Limits, Yield Points, Ultimate Strengths, Rupture Strengths and Young's Moduli for Tensile (Theraband), Relaxation (Theraband) and Compression (Bone) Load-to-Failure Tests

	Tensile Stress (Theraband)	**Relaxation Stress (Theraband)**
Initial Length (in)	5.573	5.5665
Initial Area (in^2)	0.02263	0.23175
Length Between Clamps (in)	2.7	2.736
Proportional Limit (ksi)	19.141	32.767
Yield Point (0.2%)	23.55	45.95
Ultimate Strength (ksi)	100.008	115.033
Rupture Strength (ksi)	96.844	115.033
Young's Modulus	0.1574	0.1813

	Compression (Wet Bone)	**Compression (Dry Bone)**
Initial Length (in)	4.5	3.949
Initial Area (in^2)	0.116	0.087
Length Between Caps (in)	2.9125	2.1755
Proportional Limit	1039.369	983.73
Yield Point (0.2%)	1080.173	1046.34
Ultimate Strength (psi)	1721.759	1392.002
Rupture Strength (psi)	992.124	934.713
Young's Modulus	3.012×10^{-4}	7.53×10^{-5}

D. Shear and Bending Moment Diagrams Just Prior to Failure for 3 and 4 Point Bending Tests

Wet Bone

3 Point **4 Point**

Dry Bone

3 Point **4 Point**

E. Applied and Reaction Forces and Maximum Moment for Bending Trials

Wet Bone – 3 Point Bending

$\Sigma M_A = (-79.5)(0.63) + B(0.63+0.67) = 0$

$B = 38.53$

$\Sigma F = A + 38.53 - 79.5 = 0$

$A = 40.97$

Maximum Moment = $(40.97)(0.63) - (38.53)(0.67) = 12.05$

Wet Bone – 4 Point Bending

$\Sigma M_A = (-32.39)(0.32) + (-32.39)(0.32+0.6) + B(0.32+0.6+0.35) = 0$

$B = 31.62$

$\Sigma F = A - 32.39 - 32.39 + 31.62 = 0$

$A = 33.16$

Maximum Moment = $(33.16)(0.62) - (31.62)(0.65) = 10.41$

Dry Bone – 3 Point Bending

$\Sigma M_A = (-60.37)(0.63) + B(0.63+0.67) = 0$

$B = 29.26$

$\Sigma F = A + 29.26 - 60.37 = 0$

$A = 31.11$

Maximum Moment = $(31.11)(0.63) - (29.26)(0.67) = 8.99$

Dry Bone – 4 Point Bending

$\Sigma M_A = (-55.45)(0.32) + (-55.45)(0.32+0.6) + B(0.32+0.6+0.35) = 0$

$B = 54.14$

$\Sigma F = A - 55.45 - 55.45 + 54.14 = 0$

$A = 56.76$

Maximum Moment = $(56.76)(0.62) - (54.14)(0.65) = 18.30$

F. Failure Diagrams for Bone Compression

Wet Bone

Dry Bone

DISCUSSION

A. The true strain is appropriate for analysis of the Therabands and analysis of bone is engineering strain which is the change in length divided by the original length. The true strain measurement is generally used for large strain and is calculated by using the natural log.

B. The load-extension curves obtained for blue Therabands at 2 and 5 in/min have a greater overall strength during relaxation tests than during constant loading. This is because the specimen was loaded for 30 seconds at 2 in/min, paused for 2 minutes and then loaded again until failure at 5 in/min. The specimen could adjust to the force at the initial 2 in/min, allowing a greater load to be applied before failure.

C. Therabands are used mostly in physical therapy to improve muscular endurance and strength, range of motion and flexibility. The yellow Theraband gives the least resistance and therefore can be used initially during rehabilitation. Next, the green has medium resistance and can be used next in progression. The blue Theraband gives the greatest resistance and can be used last in rehabilitation. Only the blue Theraband was tested in this laboratory, giving a Young's Modulus of 0.1574 and an ultimate strength of 100.008 ksi. Compared to the other Theraband colors, the blue Theraband will give a larger Young's Modulus and ultimate strength and a lower strain value.

D. Young's modulus is equal to dividing stress by strain. The Young's modulus for the wet bone was 3.012×10^{-4} and the Young's modulus for the dry bone was 7.53×10^{-5}. The Young's Modulus for the wet bone was greater than the modulus for the dry bone because the wet bone had more ductility and therefore was stronger. The differences in these values of moduli were due to the brittleness of the dry bone which fractured easily under compression compared to the ductility of the wet bone which fractured under compression but not as easily as the dry bone.

E. Bone is orthotropic thus, the fiber orientation of a bone accounts for the difference in mechanical response of bending versus compression by being stronger, stiffer and more ductile in compression whereas in bending both compression and tension occur and because bone is weaker in tension, a fracture may occur on the side that is under tension.

F. Three and four point bending tested specimens in bending stress, therefore exposing the specimen to both tension and compression. 4 point bending gives better results than 3 point bending because 4 point bending places a uniform load across a larger area than 3 point bending. That only has a limited area directly below the applied load. According to shear and bending moment diagrams for 4 point bending (Results, part D and E), it was assumed that the total applied load was equally distributed over the two top load points.

CONCLUSION

In conclusion, with the Theraband testing students found that the overall strength of the Theraband was greater with relaxation stress testing than tensile stress testing because the Therabands adjusted to force with relaxation stress so there was greater strength on the stress strain curve. One problem during the experiment was with the MTS machine, the Theraband was more likely to break near or at the clamps in early failure, instead of in the middle of the fabric, giving an unreliable result. For the wet and dry bone compression testing, it was found that wet bones representing young, typical bones were stronger in compression than dry bones, representing old, brittle bones. Bones are stronger in compression as the bone gains strength through compression because the molecules become more packed together (stronger) when compressed. One problem with the bone testing was that there were redundant curve in the stress strain curves that could have been mistaken for ultimate stress but instead were simply the bones adjusting in the caps of the MTS machine. However, this laboratory was successful in quantifying mechanical responses and investigating potential complexities and sources of error and evaluating tensile strength, yield strength, plastic and elastic deformation, Young’s modulus and relaxation