A Study on Organic Epoxy and Hemp Composite Plates with an Emphasis on Mechanical and Finite Element Analysis

June 7, 2012

Alma Melendez [1]

Aerospace Engineering, California Polytechnic State University, San Luis Obispo, California, 93407

Several vibration and tensile tests were conducted for four natural fiber hemp composites in order to observe its behavior and acquire the material properties of hemp. Two plates were made on the Cal Poly press table, while the other two plates were made on the Cal Poly vacuum table. All four plates are made of 100% hemp under three different types of weave. The first plate is called CTPT-12, has a thickness of 0.053 inches, and was made on the press table. The second plate is called CTL4 with a thickness of 0.152 inches and made on the press table. The third plate is called HL-10 with a thickness of 0.2145 inches, and made on the vacuum table. The fourth plate is called CTPT-12 with a thickness of 0.264 inches and made on the vacuum table. A second portion of the project was performed to further study the behavior of hemp composites. Several hemp plates with dimensions of 1.5 inch by 6 inch were made. These plates were manufactured in the vacuum table with four layers of CTPT-12 material and a 1 inch by 1.5 inch delamination. The results indicated a maximum stress of 118280 psi and a maximum displacement of 2 inches from end to end. Each plate was made with organic epoxy under a curing cycle that lasted about a day at a temperature of 150° F. Each plate had a different material property due to its different weave and manufacturing process.The plate that resisted the highest force and the highest Young's Modulus was the fourth plate with 704 lbf and 937 ksi, respectively. Plate 2 resisted the least with a force of 278 lbf and a Young's Modulus of 554 ksi. Plate 3 had the lowest Young's Modulus of 513 ksi with a force of 379 lbf. The vibration sweep ranged from 5 Hz to 1000 Hz with varying control amplitude throughout the run. The results indicated that there were significant differences between the four plates. The first plate had the highest natural frequency of 69.93 Hz at a distance of 4 inches from the surface of the aluminum blocks holding the plate for the vibration test. Plate 2 had the lowest frequency of 5 Hz when the accelerometer was placed 8 inches from the surface of the aluminum blocks. The experiment concluded that the experimental values and the finite element analysis had some similar results.

Nomenclature

A	=	cross-sectional area	(in^2)
E	=	Young's modulus	(psi)
F	=	average force load	(lbs)
G	=	shear modulus	(psi)
l	=	average length	(in)
v	=	Poisson's ratio	
Δx	=	average change in length	(in)

[1] Undergrad Student, California Polytechnic State University 1 Grand Avenue, San Luis Obispo, CA, 93407

I. Introduction

Plates can be modeled to represent complex structures in airplane wings, bridges, spacecraft antennae, and other plate-like structures. Therefore, analyzing the theoretical and experimental structural plates under certain loading conditions will help to understand the behavior of actual structures with similar conditions[1]. A recurring problem in spacecraft design, is determining the dimensions of plate elements in order to prevent harmful deformations due to buckling[2]. In space-vehicles, buckling can cause undesirable degradation in the aerodynamic profile, failure, fatigue, or aeroelasticity phenomena[2]. Natural frequency of plates must also be determined to better understand the vibrational considerations when designing its structure.

The natural frequency and resonance of a system can be desirable or undesirable. Natural frequency is the frequency a system oscillates at, once it has been disturbed[3]. In musical instruments, the natural frequency is desirable because it provides the operational vibrations for musical instruments to create musical notes. While, undesirable vibrations are in the form of wasted energy and noise in most mechanical systems. Natural frequency can be obtained by free or forced vibrations. Free vibration occurs when a mechanical system is set off with an initial input and allowed to vibrate freely[3]. In contrast, forced vibration occurs when an external force or motion is purposely applied. Resonance is the buildup of large vibration amplitude that occurs when a structure or system is excited at its natural frequency[3], which can be desirable or undesirable depending on the system. In musical instruments, resonance is a desirable result when played or tuned at its natural frequency. Undesirable mechanical resonances can be extremely harmful to mechanical systems, such as, buildings, bridges, spacecraft, aircraft, and other machinery. If a structure is forced to oscillate at its natural frequency, the system could fracture or fatigue during the time of resonance.

In the aerospace, automobile, and construction industry, composites have become very popular due to its weight to strength ratio. Composites provide needed properties that the combined materials offer. Some designs could require high strength and high electrical conductivity. Composites exhibit desirable physical and chemical properties that include lightweight properties with high stiffness and strength along the direction of the reinforcing fiber. Composites are replacing metal components due to its good weight to strength ratio. The aerospace industry is using composites more to reduce mass and still provide the required structural strength for spacecraft. A common type of composite is the fiber-matrix type. Fiber is the material that improves the stiffness of the composite, and the matrix is usually a resin that further holds the fibers together. Composites are made from embedding the fibers or particles in a continuous matrix of a polymer, metal, or ceramic. Composites have high stiffness and strength per unit weight and in some cases, such as a metal and a ceramic matrix composite, can have high temperature performance[4]. Composite materials exist in nature almost everywhere and one of the best examples is wood. The grain seen in wood is strong in tension, while the supporting matrix of lignin is strong in compression. Wood tends to have different material properties with and against the grain, which is not only a characteristic of wood, but of most modern composites. Another natural fiber composite that is becoming more popular is hemp, as seen in Fig. 1

.

Figure 1: A graphic of a hemp composite used for furniture[5].

Hemp has mainly been used in the industries that make paper, textiles, biodegradable plastics, construction, food, and fuel. Hemp is environmentally friendly because it does not require many pesticides. Hemp is being used for clothing due to its durable and strong qualities. As part of this report, hemp will be used to make plates and mechanically tested. These results should provide a better understanding of the strength hemp fibers and weaves produced.

The main objective of this report is to compare theoretical and experimental results regarding four natural fiber plates made from hemp. These plates are vibrated using the Cal Poly shaker table and were cut into strips and tested in the Cal Poly Instron machine to acquire natural properties of hemp. The purpose of the experiment is to acquire the natural frequencies and generate graphic representations of each plate's frequency response. The second part of the experiment compares the theoretical and experimental analysis of the plates. Each plate will be modeled on GeoStar and results acquired from COSMOS. These results will further increase our knowledge and understanding of hemp natural fiber plates.

II. Apparatus and Procedures

In this experiment, the natural frequencies were obtained from the Cal Poly shaker table. The hemp plates were secured in the vertical position of the shaker table between aluminum solid blocks and the surface of the table. The aluminum block was screwed to the shake table with the hemp plate in between. Two accelerometers where placed to record data from the vibration table. The control accelerometer was placed on the aluminum block surfaces, while the other accelerometer was placed on the aluminum plate, as seen in Fig. 2. Note that the accelerometers must be placed perpendicular to the surface of the vertical shake table. The two accelerometers are then connected to the main computer through two channel ports with the first

port designated for the control and the second for the plate's accelerometer. An illustration of the set-up is depicted in Fig. 2 showing the connections, shaker table, and computer.

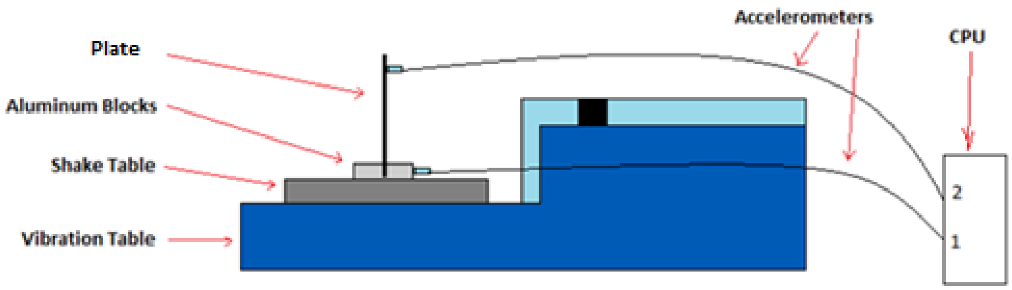

Figure 2: Side view of the lab set-up for the hemp plate vibration tests.

In order to run the experiment, the vibration table must be turned on to heat the oil. Once all connections from the shaker table to the computer are made, the frequency software can be loaded and run. The program used for this experiment was WinII, which allows the user to input a range of frequencies and place an initial acceleration onto the accelerometers. For this experiment, the frequency ranged from 5 Hz to 1000Hz in a sinusoidal sweep. The control accelerometer was set at different g levels which can be seen in the results section of this report. After setting the correct criteria, the gain was turned up to its maximum, the two power ready buttons were pushed, and the experiment commenced. The program graphed the frequency response of the aluminum plates by g's experienced over the frequency range.

In order to determine the material properties of the composite hemp plates, the Instron machine from the Cal Poly aerospace composites lab was utilized. The set-up for the Instron machine is seen in Fig. 3.

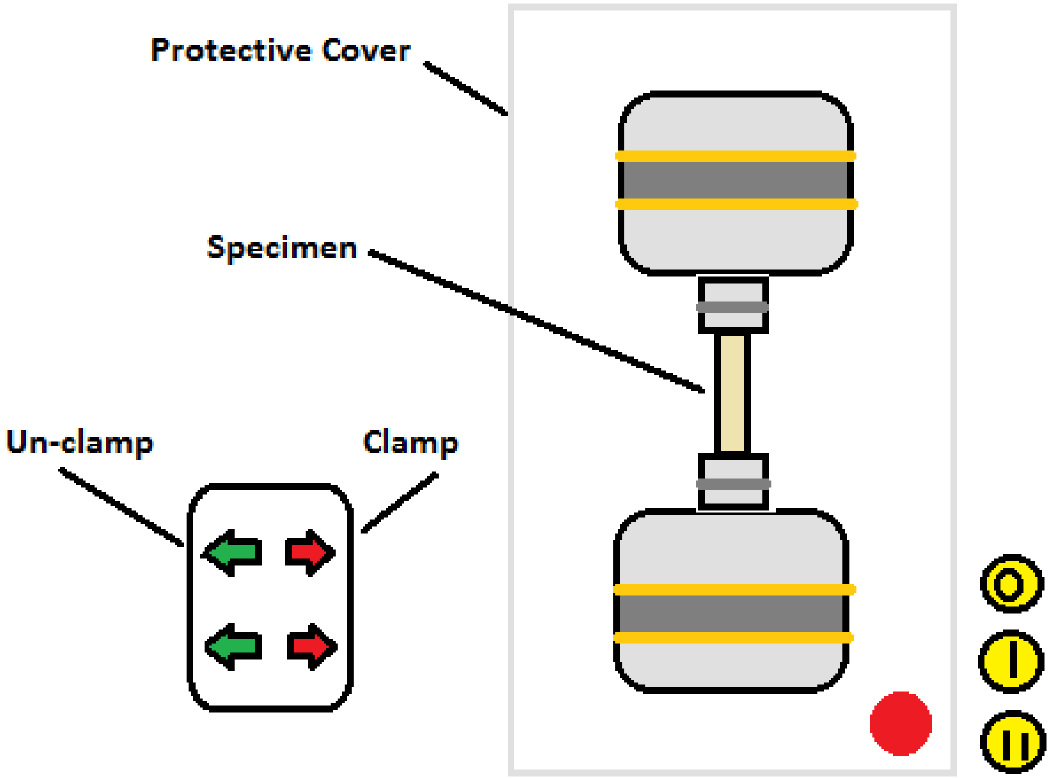

Figure 3: Set-up of the Instron machine used for tensile testing.

To utilize the Instron machine several steps must be followed. The handle located outside of the lab that belongs to the Instron machine must be pulled up to turn on. Then the automated switch and the computer must be turned on. Once the Instron machine computer is activated, it must be calibrated under the set-up label. The calibration option must be selected two more times. Then the restore option must be selected. Once the computer with the Bluehill software is activated, the program must be opened. To prepare the tensile test under the Bluehill program, the carbon fiber tensile strength test must be chosen. To get the actual machine ready for testing, the red button must be pressed for several minutes until the cables move. The yellow buttons, as seen in Fig. 3 must be pressed from 0 to II in an orderly fashion. Then place the specimen that will be tested into the machine. The specimen tested was1 inch by 10 inch. About 7 strips for each plate were tested to get a good estimate of the average value of the material properties.

To second portion of the project utilized the Instron machine to test the behavior of the hemp composite plate with CTPT-12 material. The setup of this experiment is shown in Fig. 4. The figure shows a plate that measures 1.5 inch by 6 inch that is constrained at one end. The other end contains a hinge at each side that is attached to the clamps of the machine. The test is a tensile test that separates the clamped ends with the help of the 1 inch by 1.5 inch delam in between the layers.

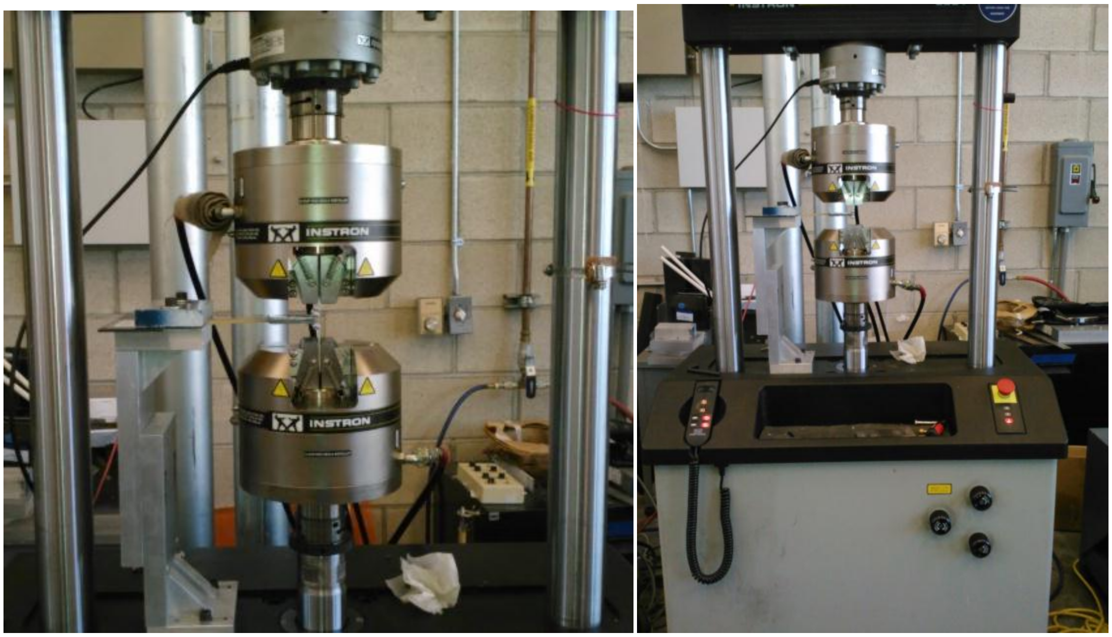

Figure 4: Setup of the hinge specimen for the 2nd portion of the project.

The left end was constrained by a device that is bolted on the Instron machine. The height of the device can be adjusted. This device is installed first then the constrained end of the specimen. The Instron lower and upper clamps are lowered and raised until they are at the specified height to clamp the hinges. The hinges were glued and the plate had four layers. The delamination was placed at the end where the hinges were glued, and positioned on top and below two layers.

III. Analysis

The data table show below was used to calculate the poisson's ratio for each plate. The tensile test extrapolated the material properties for each plate. The material properties were necessary to obtained in order to model the plates in COSMOS and to analyze the stress, strain, and deflection behavior. The data values shown in Table 1 are average values for the seven strips that were tested.

Table 1: Material properties and data for the different hemp composite plates.

Plate #	Name	Maximum Load (lbf)	Extension at Maximum Load (in)	Length (in)	Area (in^2)	Young's Modulus (psi)	Poisson's Ratio
1	CTPT-12 (Press)	438.20436	0.16936	8.06696	0.05266	888465	0.12
2	CTL-4 (Press)	248.02648	0.18711	7.98618	0.0395	554559	0.03
3	HL-10 (Vacuum)	364.29645	0.21986	8.01786	0.05905	513993	0.14
4	CTPT-12 (Vacuum)	665.54675	0.18905	8.00893	0.06367	937067	0.06

It can be seen that the vacuum CTPT-12 had the highest maximum load and Young's Modulus value. The CTL-4 had the lowest maximum load; however, it did not have the lowest Young's Modulus. The HL-10 had the lowest Young's Modulus value due to the fact it was only capable in holding the least amount of stress.

A set of equations were used to determine the poisson's ratio for each plate. The shear modulus must be found first in order to determine the poisson's ratio, v. The following equation was used to calculate the shear modulus, G,

$$G = \frac{Fl}{A\Delta x} \tag{1}$$

where F is the average force load, l is the average length of the vertical strips, A is the average cross-sectional area of the vertical strips, and Δx is the average change in length. After the shear modulus, G, has been found, the poisson's ratio can then be calculated using the equation,

$$v = \frac{E}{2G} - 1 \tag{2}$$

where E is the Young's Modulus and G is the shear modulus.

IV. Finite Element Analysis

The numerical analysis software used for this experiment was the finite element software of COSMOS and GeoStar. The pre-program, GeoStar, allows the user to create a representation of the structure and the loads that are being applied. COSMOS is the post program which calculates the stress, deflection, natural frequency, and various other solutions that are created in GeoStar. Through implementing the geometry, material properties, mesh, loads, and boundary conditions into the finite element program, an approximate solution can be acquired. Using the measurements from the natural fiber composite plates, the geometry is first generated on the program. The material properties and the element selection are the next components that are applied to the finite element model. The element type is a Shell4 element, selected under the material properties tab. For plate 1, 2, 3, and 4 the thicknesses were 0.053, 0.0337, 0.0616, and 0.0648 inches respectively. Each thickness was inputted as a real constant under the material properties tab. The Young's modulus inputted for plate 1, 2, 3, and 4 were 888 ksi, 554 ksi, 513 ksi, 937 ksi respectively. The poison's ratio inputted for plate 1, 2, 3, and 4 are listed on Table 1. The meshing of the model was determined to have 40 elements by 40 elements for the 10 by 10 inch plate. Once the model is meshed, the boundary conditions are applied to the base of the model with a height of 1 inch in the vertical direction, as seen in Fig. 5

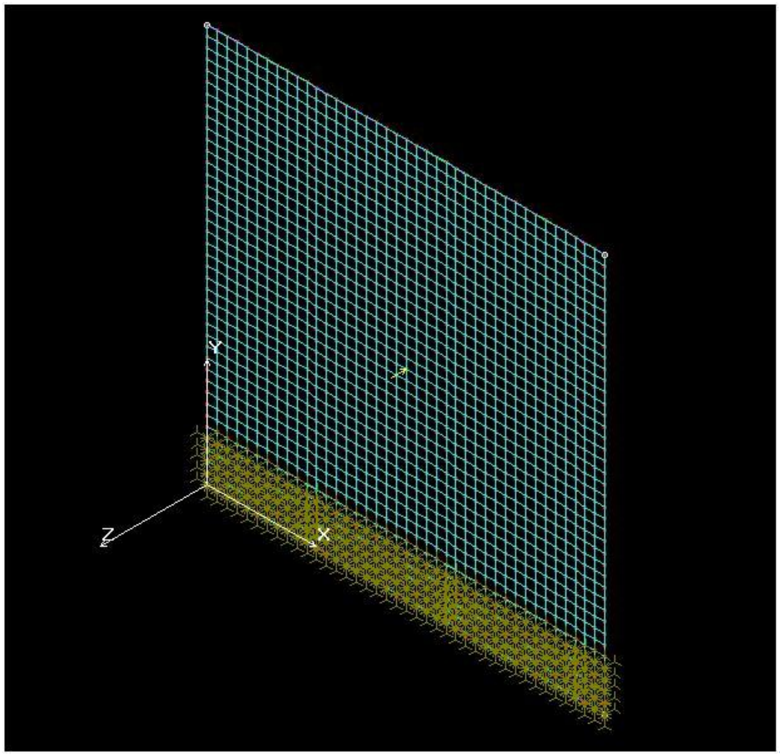

Figure 5: GeoStar's representation of the geometry for the hemp composite plates.

The natural fiber composite plate is constrained in all three degrees of freedom. The force is applied at the center of the plate to model the case when the accelerometer is 4 inches from the surface of the aluminum block. The force applied is approximately 0.7 lbf in the –z direction, which was based off the accelerometer's weight. The final procedure for generating the approximate solution of the experiment is to run the static analysis under the analysis tab. Each hemp composite plate gave a different result, which will be explained in the results section of this report.

V. Results and Discussion

An analysis for each hemp composite plate was made based on its different material property and natural frequency. Plate 1 and 4 had the same material of CTPT-12. However, plate 1 was manufactured in the press table from the Cal Poly Aerospace Composites and Structures Laboratory, while plate 4 was manufactured on the vacuum table. Plate 2 had a material of CT-L4 and made on the press table, while plate 3 had the material of HL-10 and made on the vacuum table. All of the four plates had a curing cycle of 150 ° F and were each made within 24 hours.

The frequency response of each plate was obtained by using WinII program, which provided a graphical representation of the data. Figure 6 displays the data generated from the vibration test software for all four plates with respect to their amplitude and frequency at a distance of 4 inches from the surface of the aluminum block. The natural frequencies for each plate are represented at every peak on the graph. Based on the experimental results, plate 2 with

the accelerometer at 8 inches from the surface of the aluminum block had the highest amplitude at the natural frequency of 81.7 Hz. Plate 3 had the lowest natural frequency of 7.06 Hz with the accelerometer at 8 inches from the surface of the aluminum block.The red line (labeled as Channel 1) in Fig.6 and Fig. 7 represents the accelerometer attached to the aluminum blocks to show the vibration movement of the shaker table in comparison to the accelerometer attached to the experimental plate. It is important to understand that the amplitude of vertical and horizontal position will vary because each test had different control amplitude, which will change amplitude value for each plate.

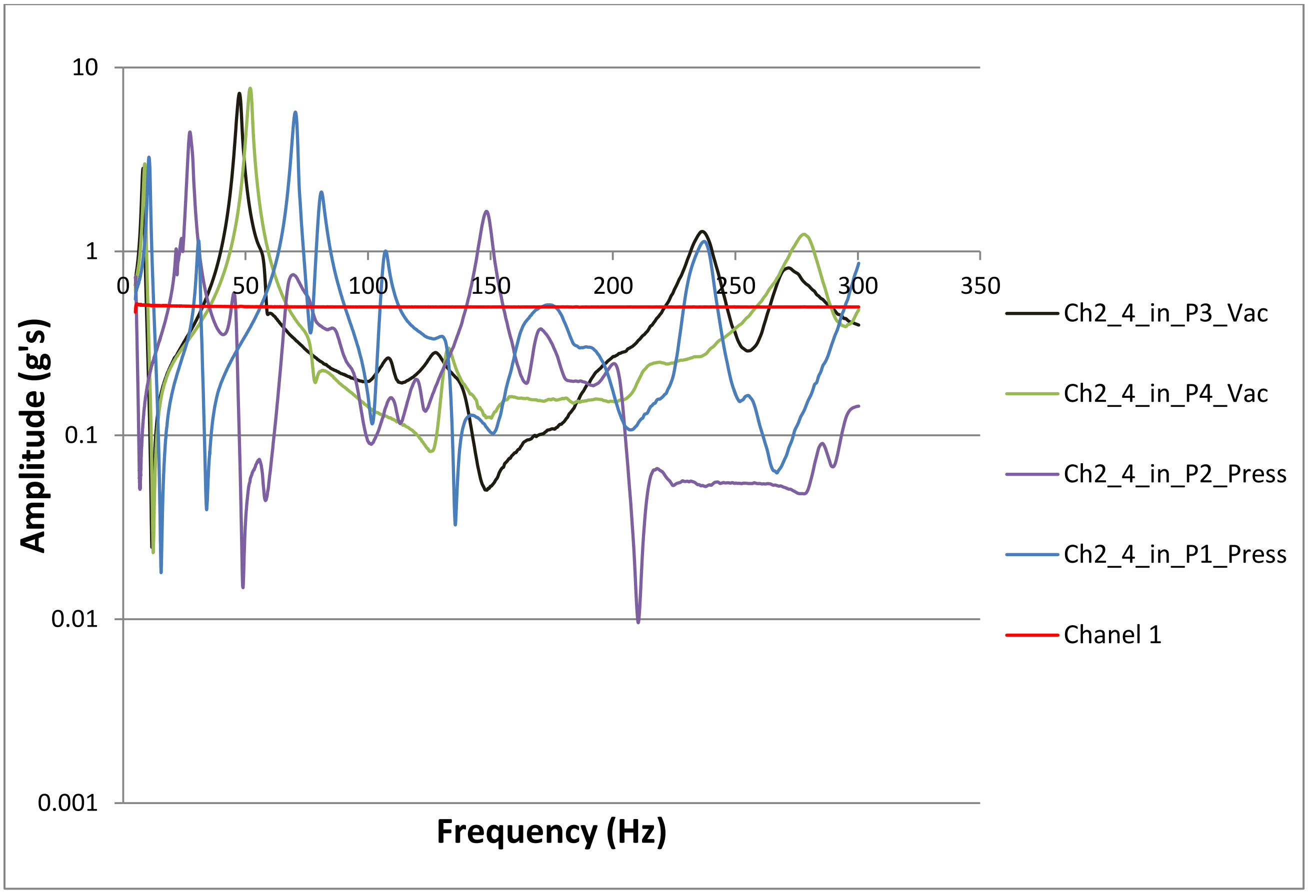

Figure 6: Representation of the frequencies of each plate with the accelerometer at 4 inches.

Based on Fig. 6, the highest natural frequency is from plate 1 at approximately 69.93 Hz. Following closely behind is plate 4 with a natural frequency of 51.49 Hz. Plate 2 and plate 3 had the lowest natural frequencies at 27.02 Hz and 47.14 Hz. The desired plate is the first one because it has the highest frequency. That means that this plate is very stiff because it deflects very little compared to the rest of the plates.

Figure 7 represents the frequencies of the plates with the accelerometer at a distance of 8 inches from the surface of the aluminum block. Based on this figure, the highest natural frequency is 81.75 Hz for plate 2. Plate 3 and 4 had similar natural frequencies at 7.06 Hz and 7.75 Hz, respectively. Plate 1 had a natural frequency at 9.09 Hz. This means that plate 3 had the most deflection because it had the lowest frequency. Unexpectedly, plate 2 had the highest

natural frequency, which means it deflected the least. This result is questionable, not only is it an outlier, its stiffness is one of the lowest. Therefore, when designing spacecraft or the like, one must consider the natural frequency of the material to determine the best design and stiffness.

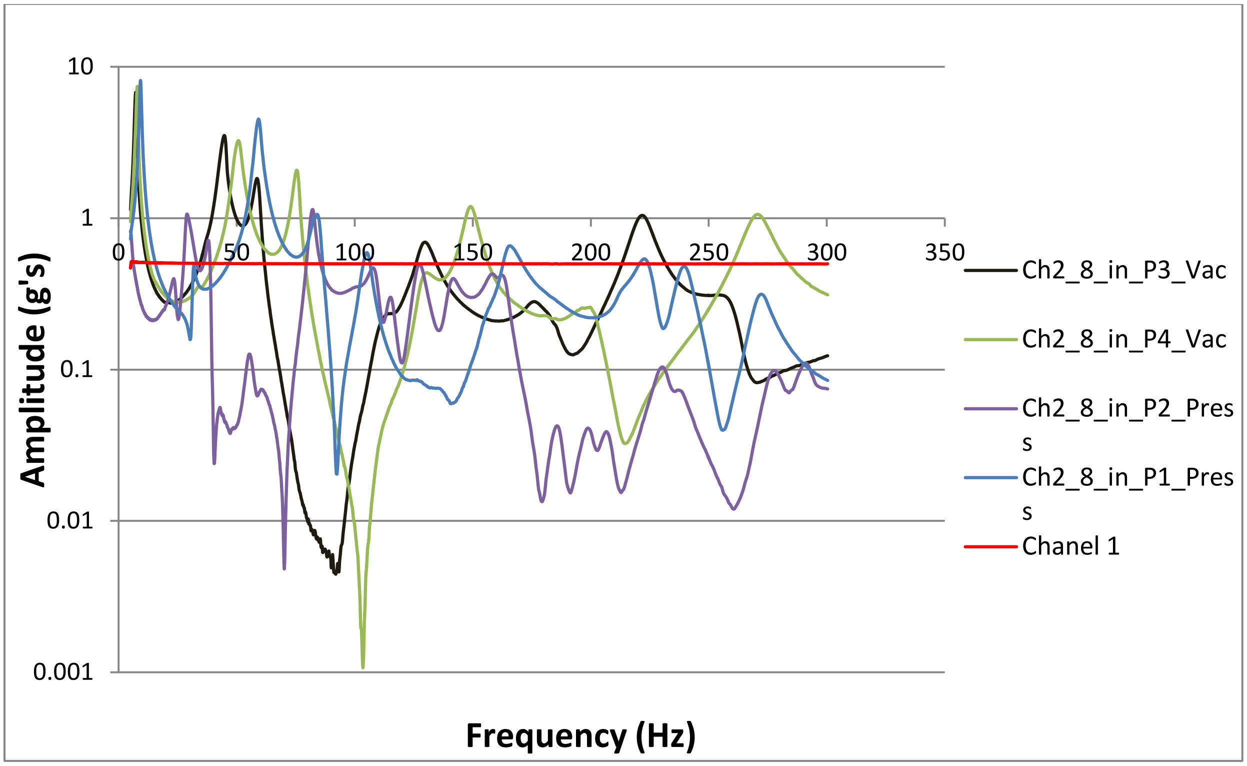

Figure 7: Representation of the frequencies of each plate with the accelerometer at 8 inches

As seen in Fig. 8, the stress-strain relationship is shown for all four plates during the tensile test. Based on Fig. 8, plate 4 was able to handle the most stress. This may be an indication that the best manufacturing method for these plates, is to use the vacuum table instead of the press table. The slope of the curve would allow a steeper trend and as a result, a higher Young's Modulus. Figure 8 indicates that plate 3 could handle the least amount of stress and would result in a less steep slope. Thus, plate 3's Young's Modulus was the lowest value compared to the four plates. Even though plate 2 was the lightest and thinnest plate out of the four plates tested, it performed much better than expected.

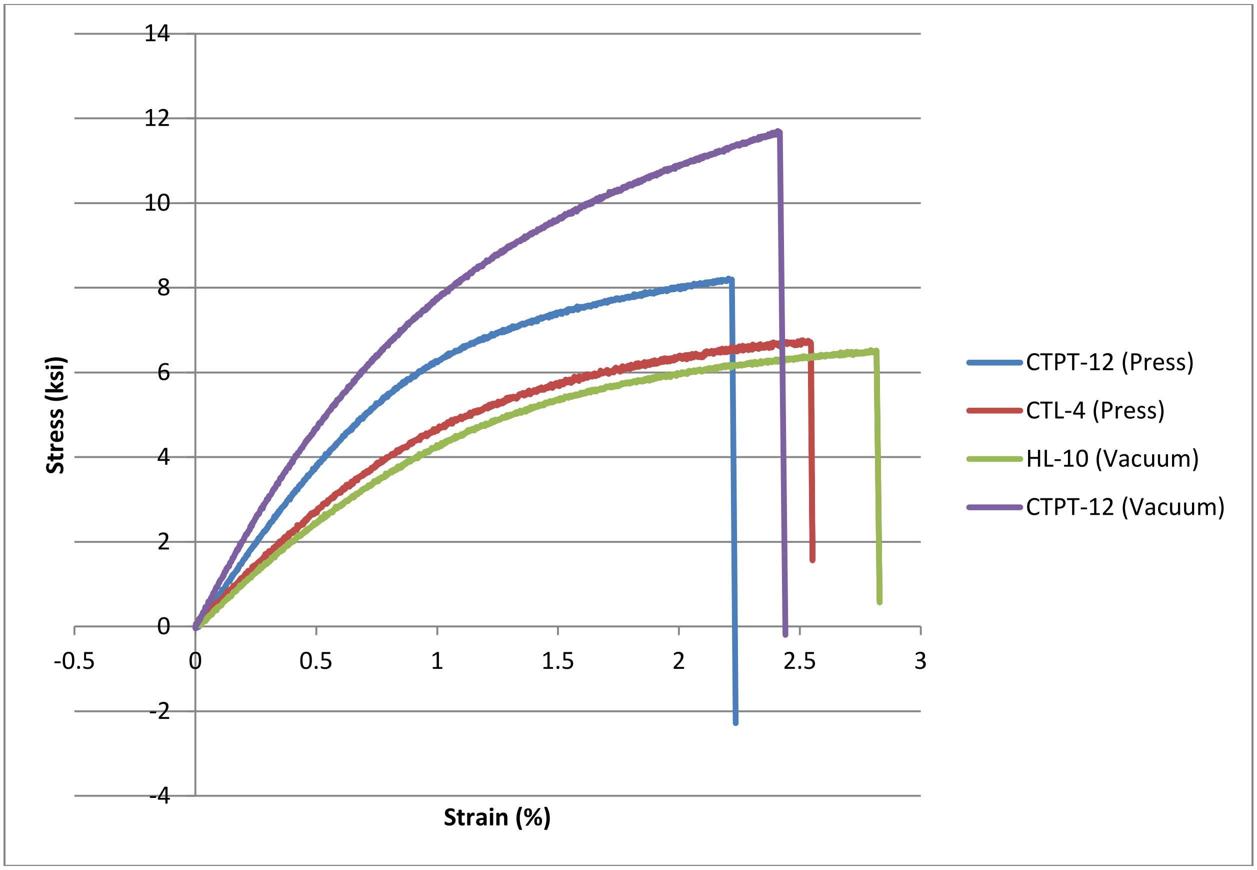

Figure 8: Stress-strain relationship of all four hemp composite plates.

Plate 2 was capable of handling a higher stress than plate 3, which had a greater thickness. Overall, the CTPT-12 material had the capabilities to handle the highest stress for both the vacuum or pressed manufactured plates. Based on Fig.8, the vacuum manufacturing method will most likely be used to cure the rest of the plates since it was able to handle the highest loads.

The purpose of Fig. 9 will help determine the Young's Modulus for each hemp plate. After the material properties have been obtained, the plates can then be modeled into COSMOS. The deflection for all the vibrated hemp composite plates can be seen in Fig. 9.

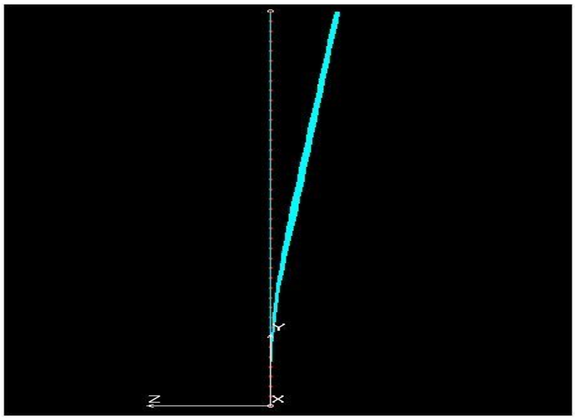

Figure 9: Typical displacement trend for all the hemp composite plates.

As seen in Fig. 10 the highest stress and strains occurs near the bottom portion of plate 1and would most likely to break near the active region due to the constraints. Plate 1 was manufactured in the press table from Cal Poly's Composite and Structures Laboratory. The material for plate 1 is CTPT-12. The constraints were based off the aluminum block about 1 inch in height to secure the plates.

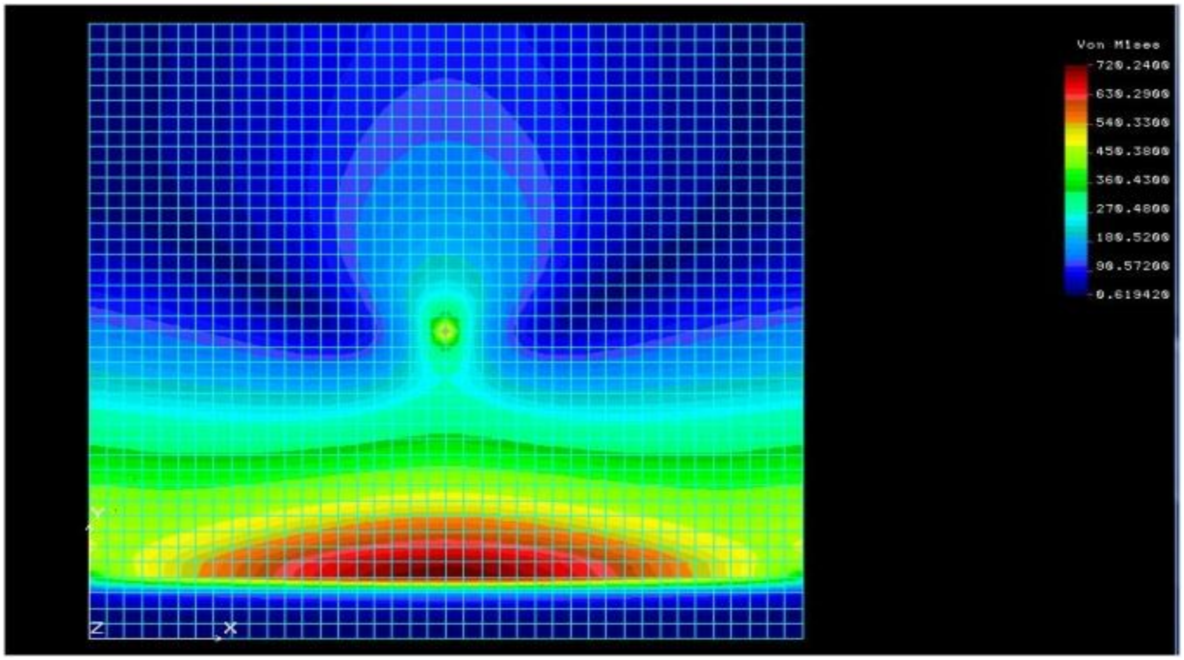

Figure 10: COSMOS representation of stress for plate 1.

Hence, the blue area that runs across the bottom plate is a representation of the aluminum blocks. The point load of 0.77 lbs creates a contour effect that heavily disperses towards the constraints. However, the top outer edges and the bottom edge do not experience much stress or strains. The maximum stress value determined in COSMOS was 720.25 psi. The maximum strain values that plate 1 experiences was a value of 0.00055. Both stress and strain figures experience similar contour behaviors as expected since it is based off the constant, Young's Modulus.

The pressed CTPT-12 plate has the highest deflection near the top edge as a result of having the constraints placed along the bottom edge, as seen in Fig. 11. The area where the constraints are placed experience low or no deflection; however, the deflection starts to increase as it moves further away from the constraints. The point load placed in the center location still creates a high deflection at the end since the end is free to bend. The maximum deflection value for plate 1 has a value of 0.045 in.

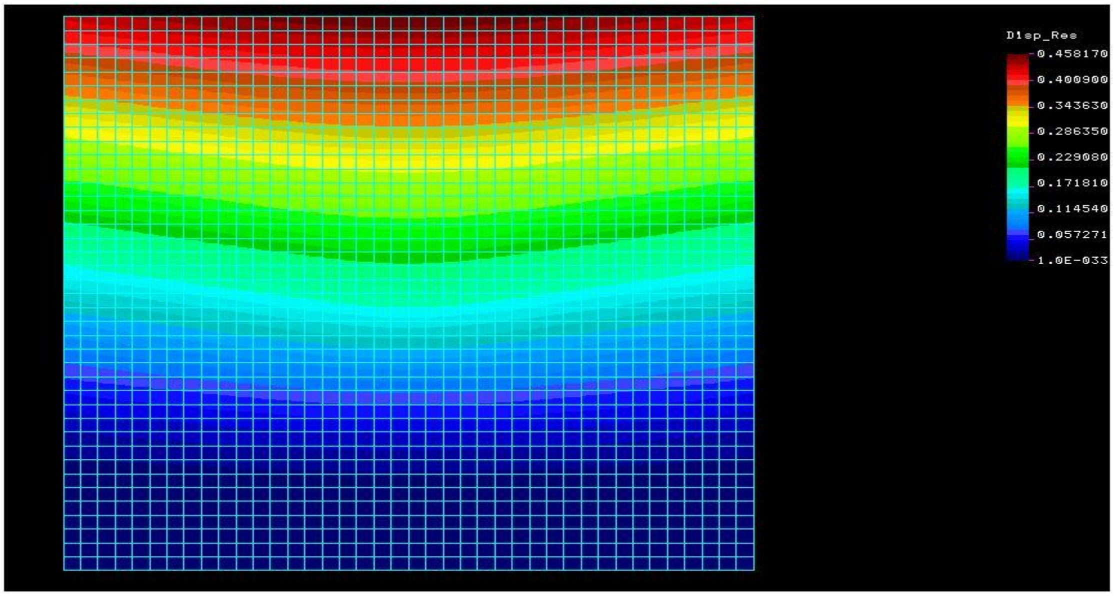

Figure 11: Displacement representation of plate 1.

Plate 4 with material CTPT-12, manufactured on the vacuum table, showed a similar behavior to plate 1. However, the stress and strain ranges were lower in comparision to the plate 1. The maximum stress value that plate 4 expriences is a value of 569.49 psi, as seen on Fig. 12.

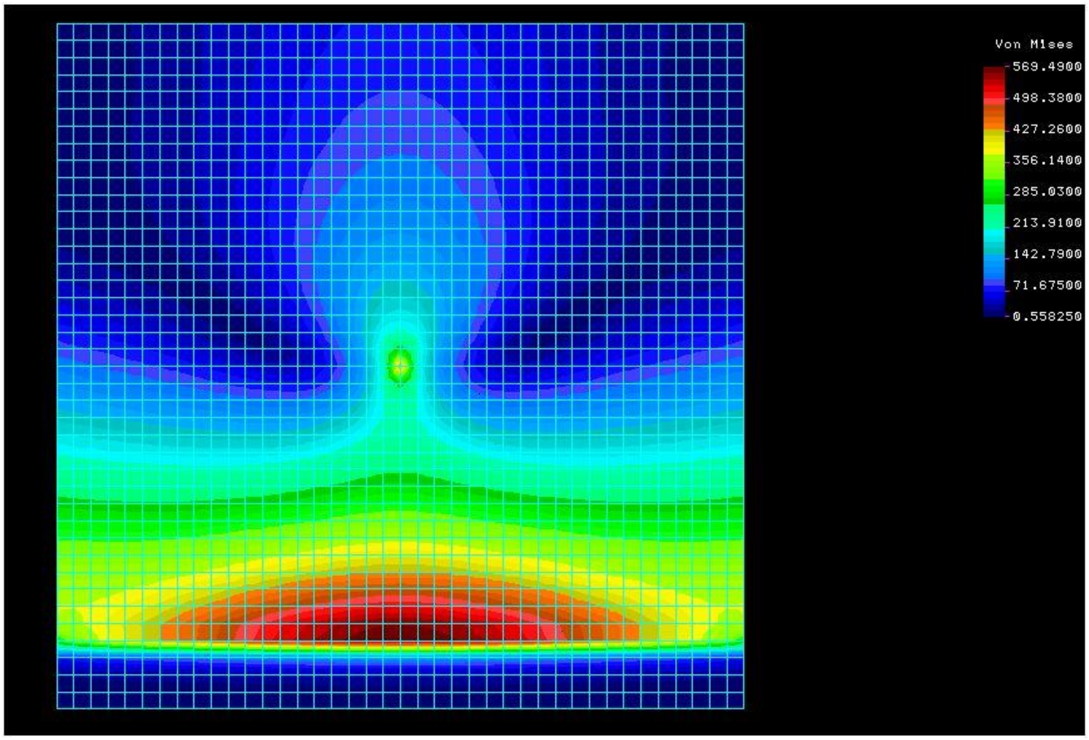

Figure 12: Stress representation for plate 4 with CTPT-12 material.

The maximum strain value for plate 4 had a value of 0.0004. It can be seen that the vacuumed and pressed plates show a difference in material properties along with the stress and strain analysis even though both plates are made of the same material.

The displacement range also decreased in comparision to the plate 1. The maximum displacement that occurs on the plate had a value of 0.30 in, as seen in Fig. 13. The contours for both vacuum and pressed CTPT-12 plates are similar. This shows that the machine used to cure the plates play a vital role in the mechanical analysis. Thus based off the COSMOS analysis, this further justifies in using the vacuum machine to cure the plates. Plate 4 was able to handle a high force loading with a high Young's Modulus, but still able to obtain the lowest stress,strain, and deflection in comparision to its counterpart, plate 1.

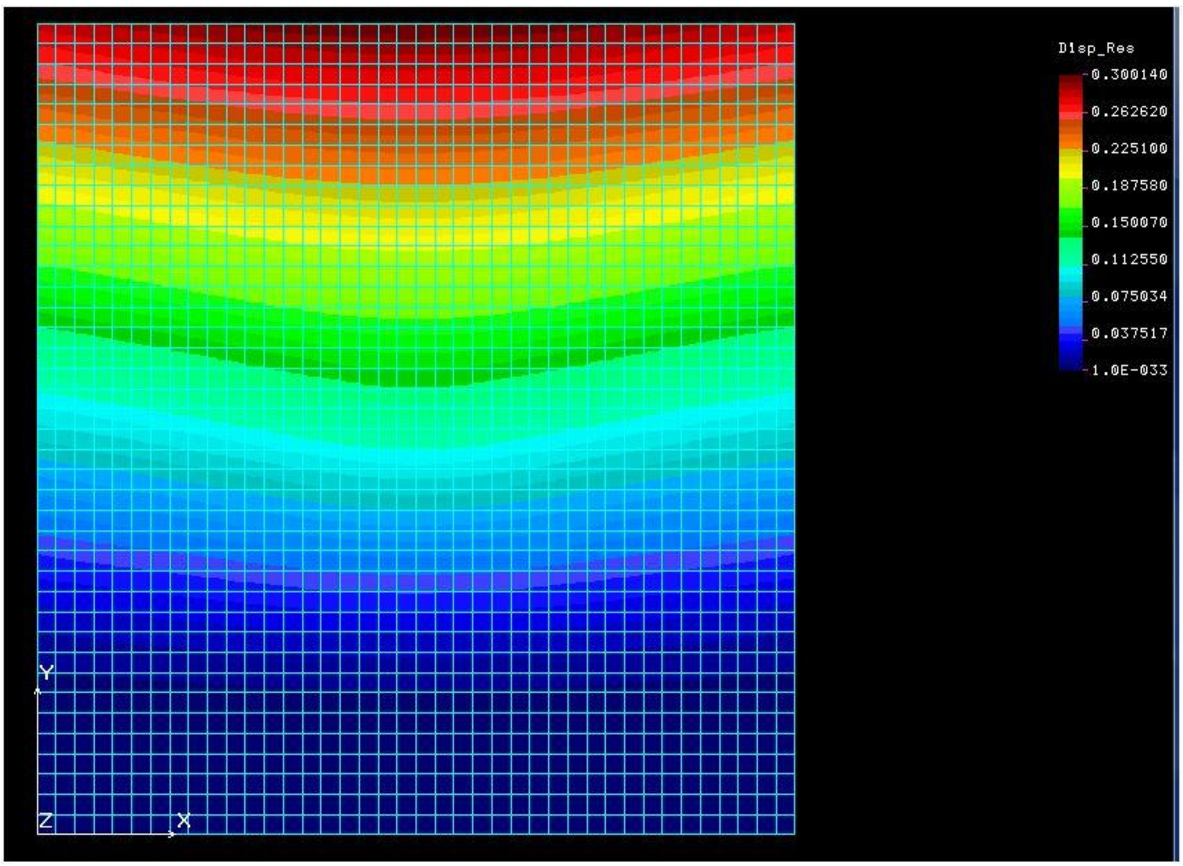

Figure 13: Displacement trend for plate 4.

Plate 2, with material CT-L4 and manufactured on the press table, shows a higher stress range in comparison to the four plates. The maximum stress value is 1289.5 psi as seen in Fig. 14.

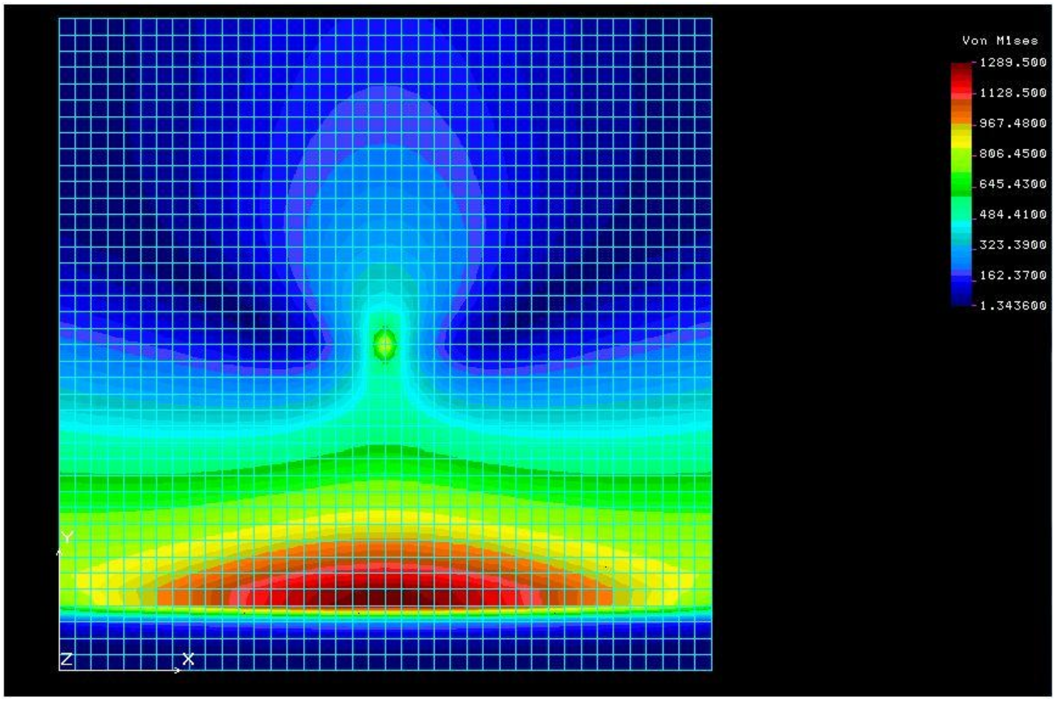

Figure 14: Stress values and stress concentrations of plate 2.

According to COSMOS, plate 2 has highest strain values with a 0.77 lb point load. This high range in stress and strain may be a result of the small thickness value of 0.03567 in. Hence, the small area would mean higher stresses which correlated to higher strain values as seen in Fig 15.

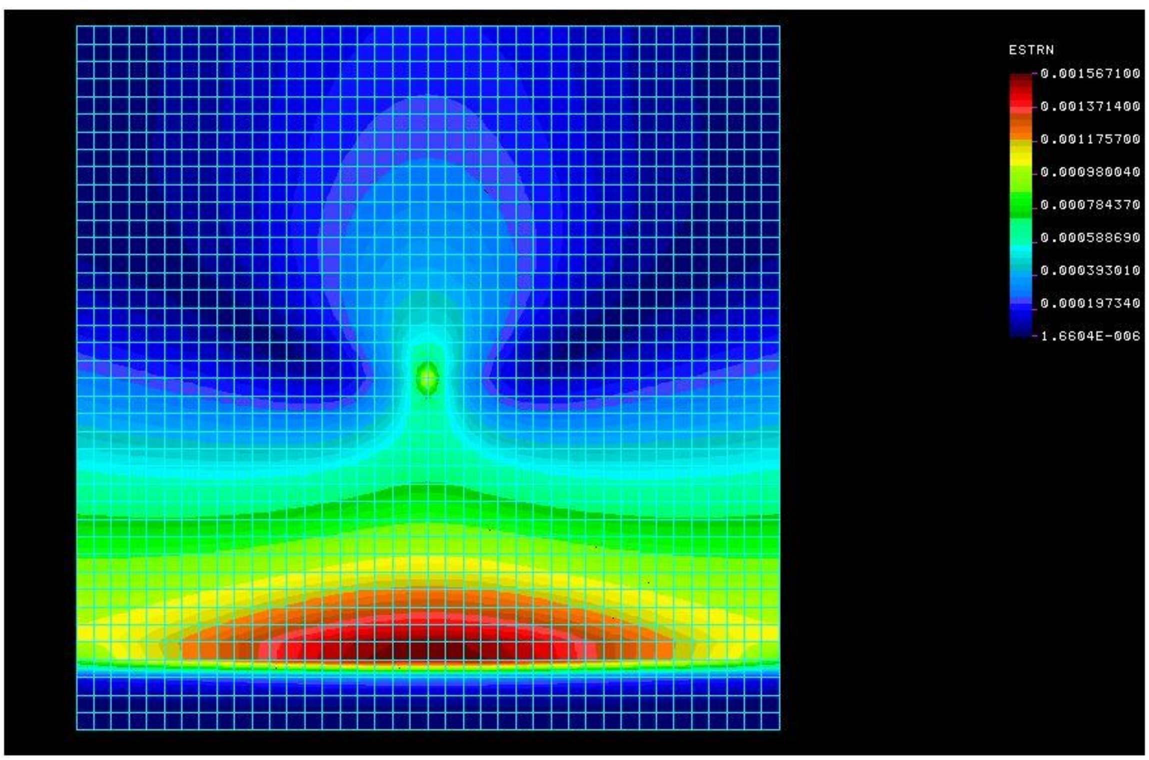

Figure 15: Strain distribution for plate 2

The maximum displacement occurs at the free end of plate 2 with a value of 1.71 inches. The thin structure from plate 2 allows the plate to freely deflect more in comparison to the plate 1 and 4, which has a greater thickness. The plate is less stiff and as a result, it is more prone to higher deflections. Plate 2 is more flimsy due to its thin structure and hence, it outputs a higher deflection, as seen in Fig. 16.

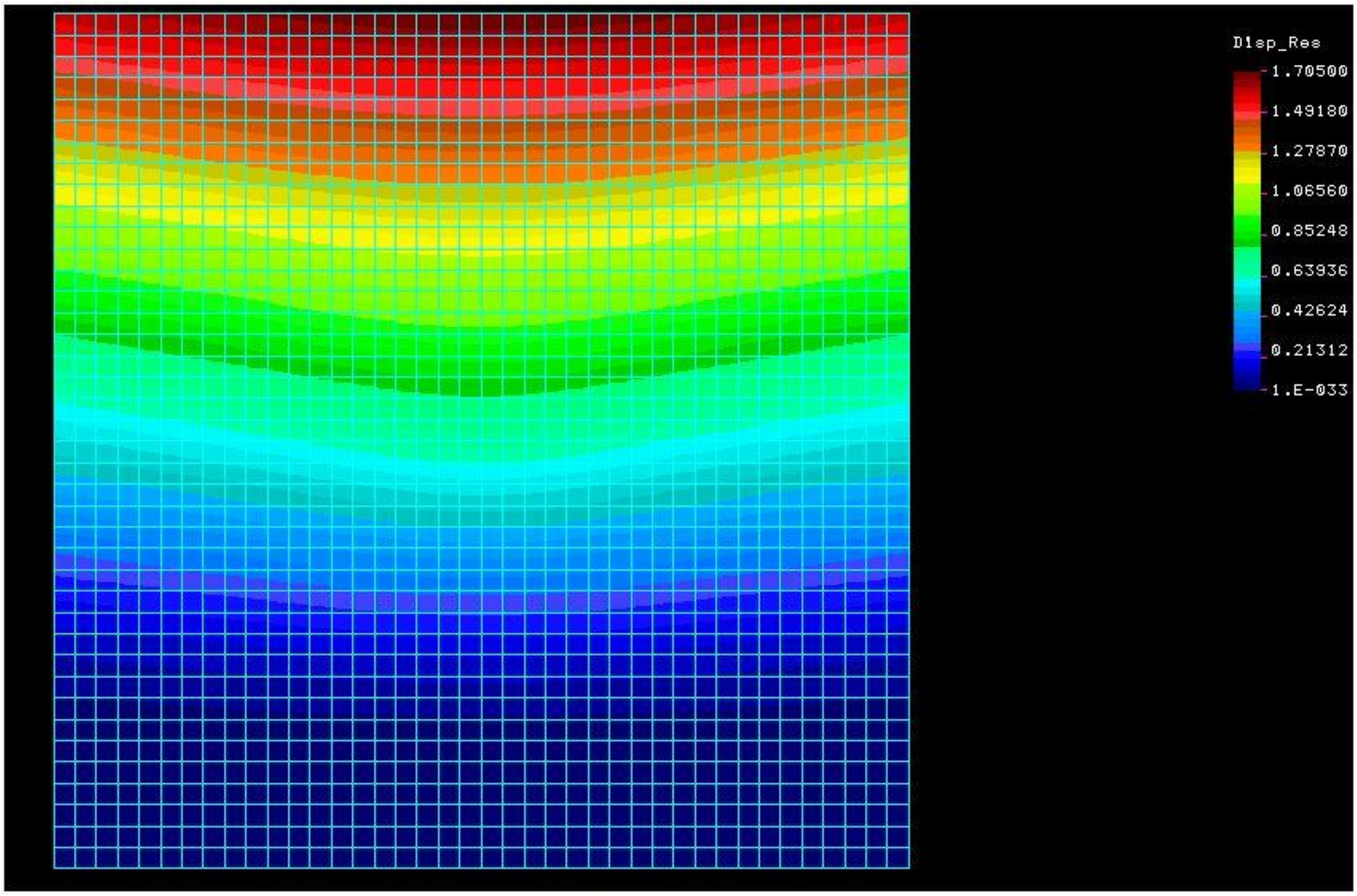

Fig. 16: Displacement trend for plate 2 with material CT-L4.

Plate 3, with material HL-10 and manufactured on the vacuum table, shows the lowest stress and strain ranges out of all the four plates. The maximum stress value that the plate has is 560 psi, as seen in Fig. 17. The maximum strain for plate 3 is 0.00075. The highest deflection for the plate outputted a value of 0.54 in. The maximum deflection occurs at the end of the plate because there are no constraints placed there. Since the point load was constant and placed on the same location for all the plates, the deflection contour for plate 3 had the same behavior as seen in previous plates. Just like the plates that have been analyzed already, the COSMOS model shows a similar contour model for the stress, strain, and displacement analysis for this plate.

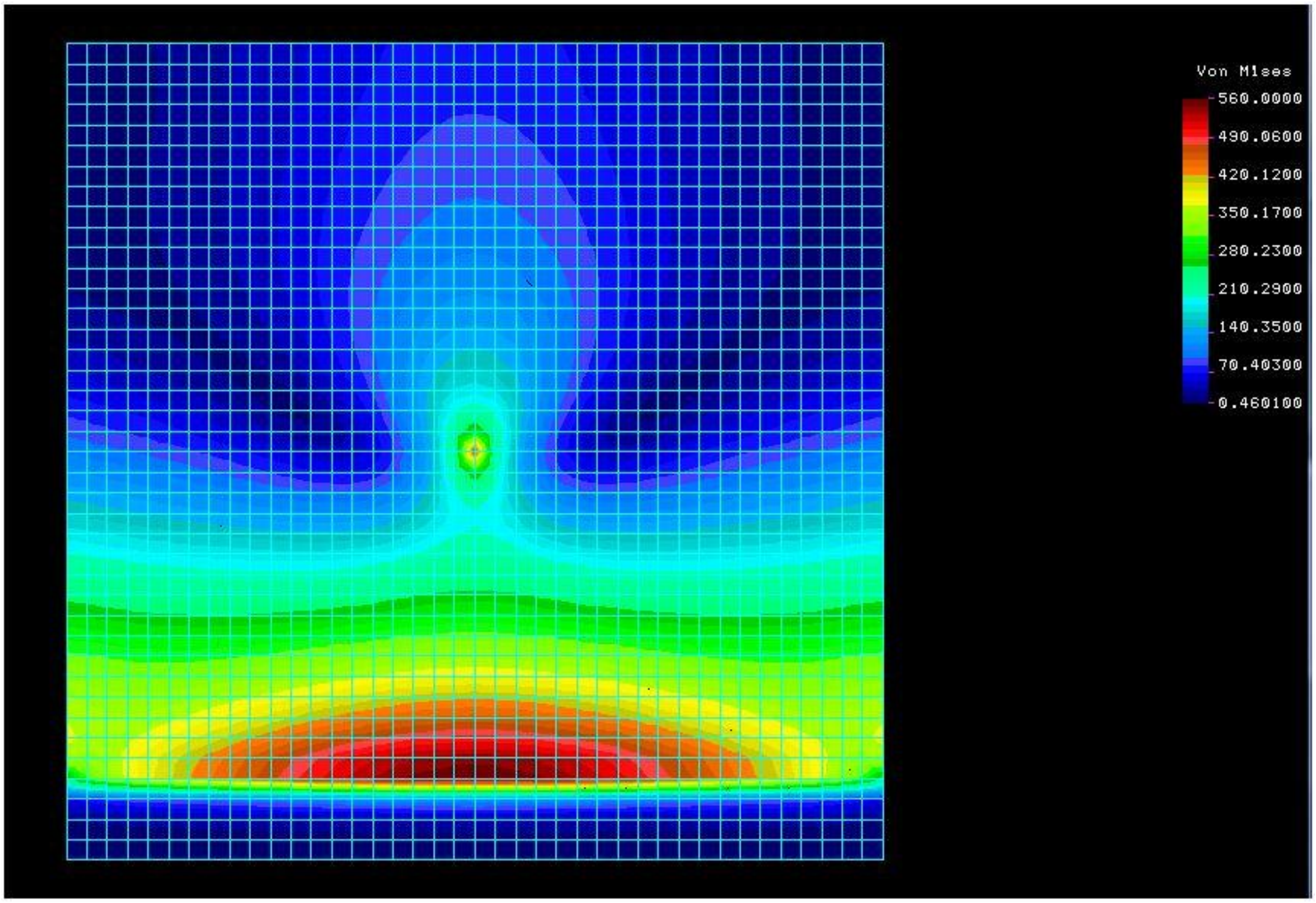

Figure 17: Stress representation of plate 3, with matrial HL-10 and manufactured on the vacuum table.

Nonetheless, there were various errors and problems that occurred during the experiment. For the experimental portion of this laboratory the plate could have been secured better to the vibration table in order to remove any miss readings from the software to the vibration table. The creation of the plates can also play a factor in the errors. During composite making, it is crucial to ensure that epoxy is properly layed-up for the whole plate. In addition, the placement of the weaves and orientation was also important. The emery cloth needed to be properly secured in order to ensure the success of the tensile test by the Instron machine. Also, during our FEA analysis, the mass of each plate was not implemented onto the model. The mass of the accelerometer was only taken into consideration for the point load. This increase of mass on the specimen would result in an increase in total mass and could change the static free vibration of the hemp plates. This would then change all the calculated numerical values and may greatly reduce the errors.

VI. Applications

To further understand the behavior of organic epoxy and hemp composite plates a second portion of the project was performed. The setup and manufacturing process is mentioned in the apparatus and procedures section of this report. This portion of the project is an application of hemp composite plates. These plates were manufactured in the aerospace composites laboratory at Cal Poly. They were tested in the Instron machine and the experimental results can be seen in Fig. 18.

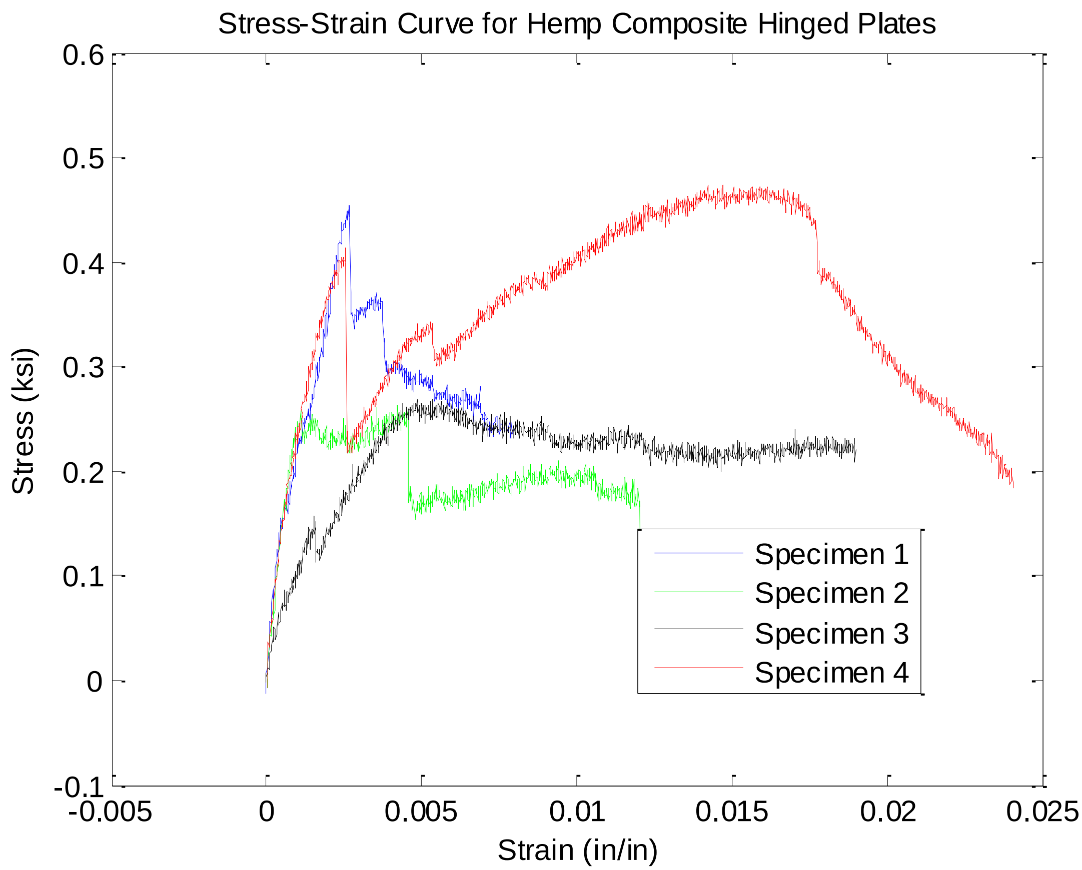

Figure 18: Experimental results of the hinged hemp composite plates.

The experimental results showed a similar trend, but were not similar. A reason for the dissimilar results could be due to the machine. The Instron machine was assembled with different parts for several weeks and the clamps may have been a little misaligned. Also the glue that attached the hinges to the composite plates took several attempts to properly glue. That tempered with the results.

The numerical analysis software used for the second section of the experiment was the finite element software of COSMOS and GeoStar. Through implementing the geometry, material properties, mesh, loads, and boundary conditions into the finite element program, an approximate solution can be acquired. Using the measurements from the natural fiber composite plate, the geometry is first generated on the program, as seen in Fig. 19.

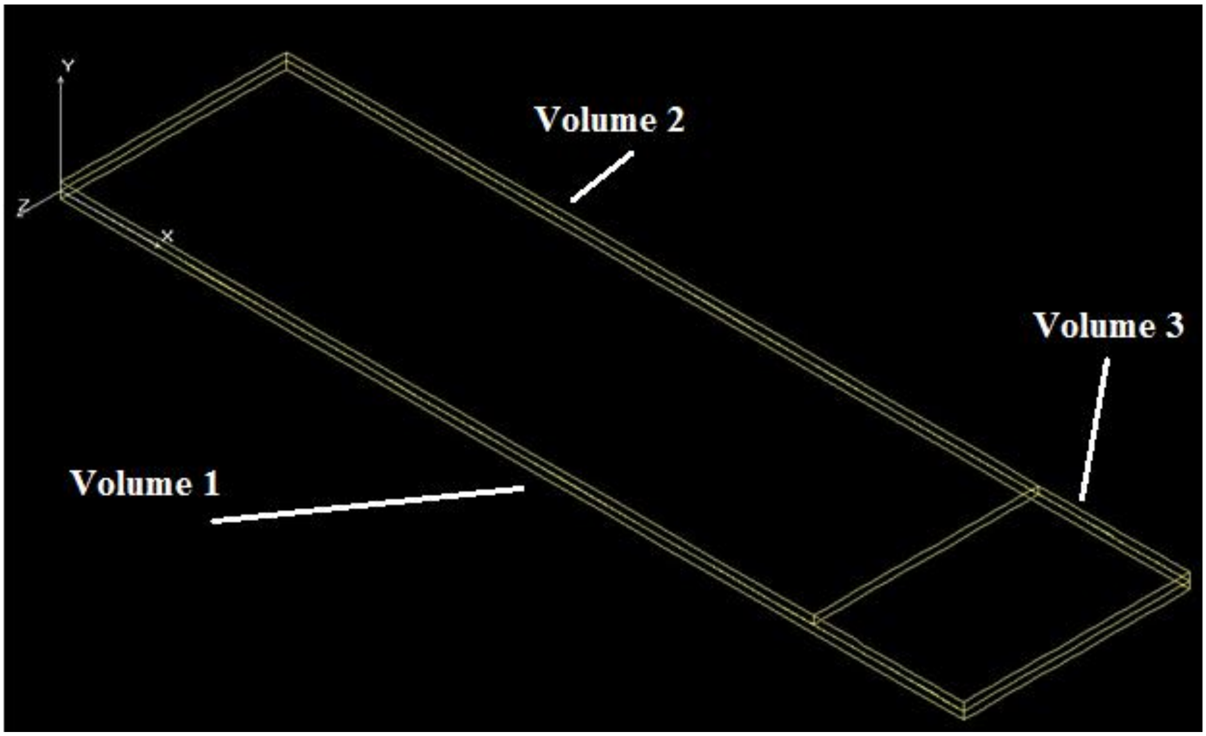

Figure 19: Geometry of the hinged plate with delame.

The length is 6 inches, the width is 1.5 inches, and the total thickness is 0.1 inches. Volume 1 and 2 were created first as surfaces and then extruded. The mesh on volume 1 and 2 were then established and merged in order to bond the two volumes. The size of each element was .05 inches. Volume 1 had 120 elements along the length and 30 elements along the width. Volume 2 had 100 elements along the length and 30 along the width. Volume 3 was created after the previous volumes were merged. Volume 3 had 20 elements along the length and 30 elements along the width. The edge nodes on yz plane of volume 3 were merged to the nodes on the yz plane of volume 2. The material properties from Table 1 for the CTPT-12 material for the plate manufactured in the vacuum were inputted into GeoStar under the propsets tab. The element type chosen was a solid since the geometry used volumes. The hinged plate was constrained in all six degrees of freedom. The hinged plate was constrained about 0.5 inches in the x-direction. The

applied force was 76 lbs in the positive and negative y-direction. The parametric mesh and boundary conditions are seen in Fig. 20.

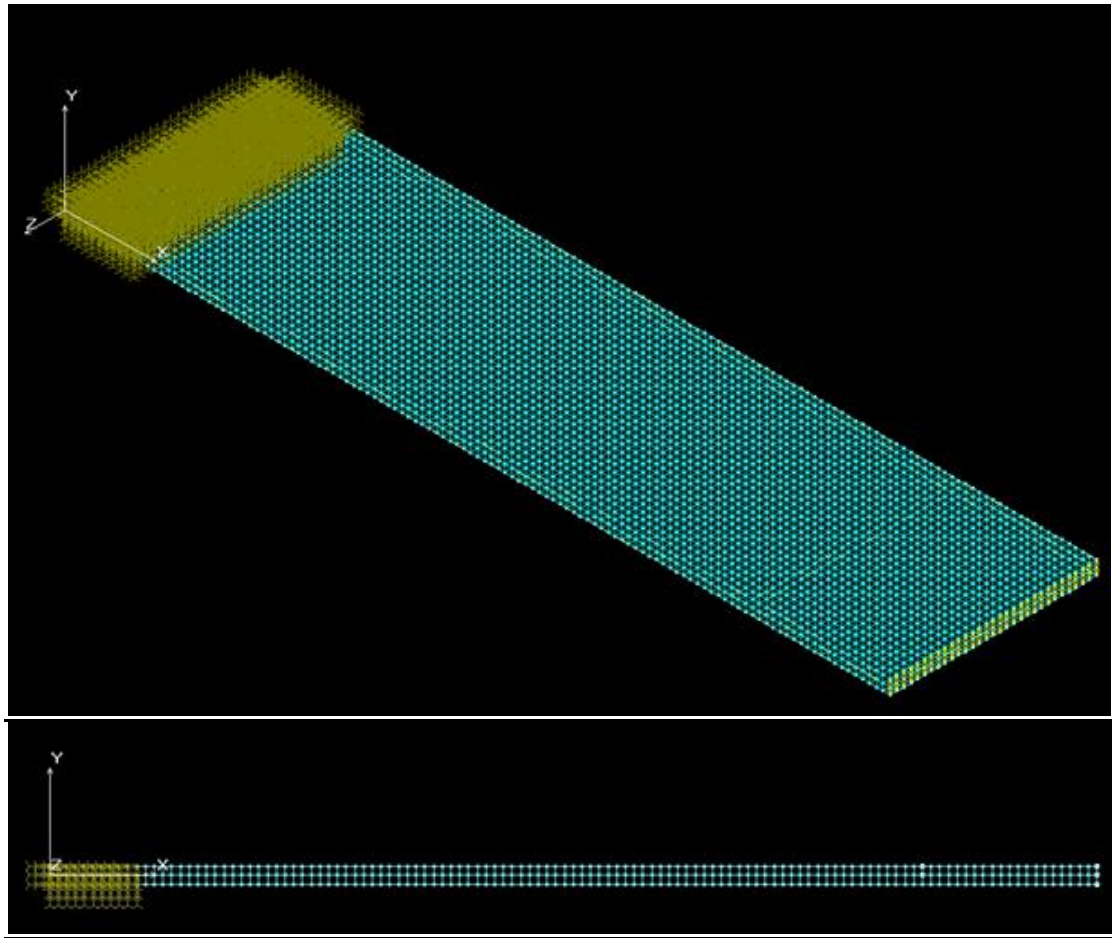

Figure 20: Parametric mesh of the hemp hinged plate with boundary and loading conditions.

The static analysis was analyzed in COSMOS under the analysis tab. The stresses and stress concentration are illustrated in Fig. 21. The largest stress concentration in near the initial crease between the delame and layers. The maximum stress is approximately 118280 psi. The hinges glued to the surfaces of the free ends on the side of the delame did not break when they were tested in the Instron machine. This helped acquire better results than previous experiments. The hinges did not need to be modeled, but for more accurate results they should.

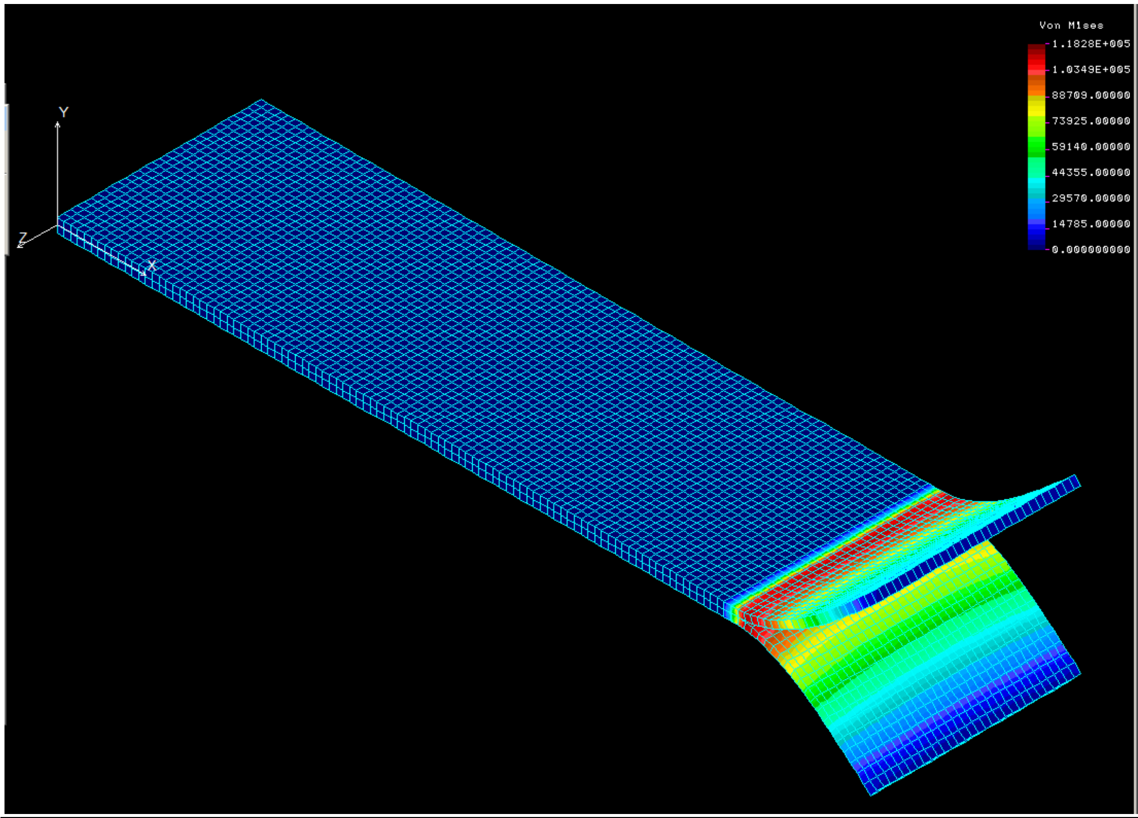

Figure 21: Stresses and stress concentration of the plate hinge composite plate.

The displacements of the test specimen was also acquired and shown in Fig. 22. The maximum displacement as shown in the figure is approximately 2 inches. This is similar to the experimental results from the Instron machine. The deformed shape is also the expected trend from the experiment.

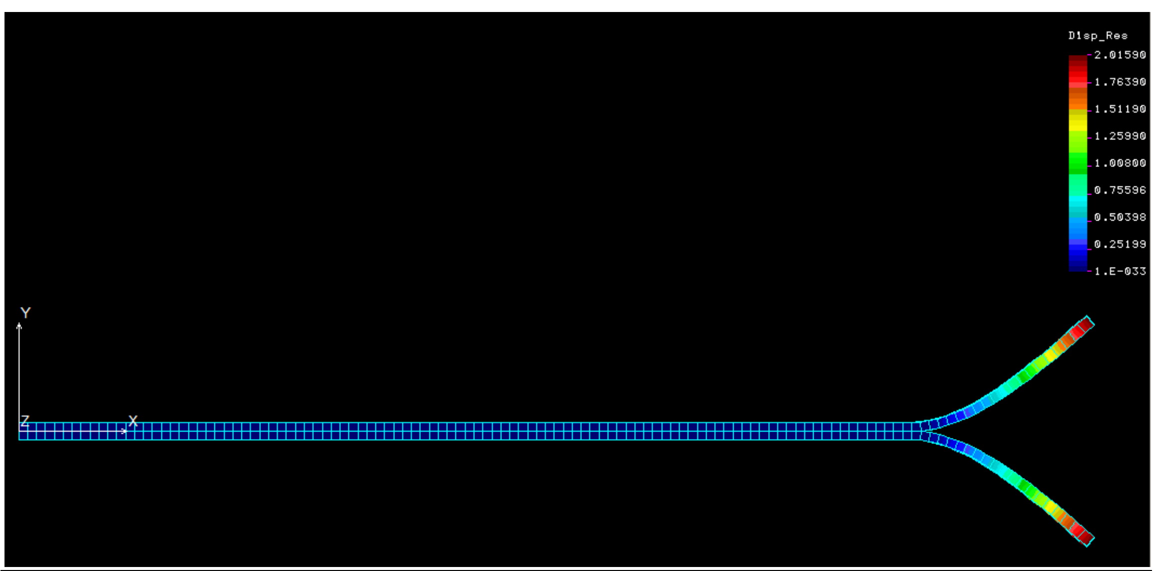

Figure 22: Displacements and deformed shape of the plate hinge composite plate.

VII. Conclusion

Through analyzing all four plates under the vacuum and press, it can be shown that the vacuum prevails in terms of allowing the plate to have a better curing cycle. For example, plate 4 was capable in handling higher force loads during the tensile test in comparison to plate 1 with the same material but different manufacturing process. The CTPT-12 material had the highest Young's Modulus than the CTL-4 and HL-10 materials. Based off the numerical analysis from COSMOS, plate 4 had the lowest stress, strain, and deflection values than plate 1. The FEA analysis further justifies that the vacuum manufacturing process is the preferred method to cure the hemp composite plates. The COSMOS model also showed that plate 2 deflected the most due to its light and thin structure. This relates to the experimental test done on the shake table. The higher the resonant frequency, the lower the deflection the material is exhibiting. For the natural frequency results of the four plates, plate 1 and 4 had the highest natural frequencies when the accelerometer was 4 inches from the surface of the aluminum blocks. The plates with the lowest frequencies occurred around 7 to 8 Hz for plate 3 and 4 with the accelerometer at a distance of 8 inches. It can be concluded that the material and weave for CTPT-12 resulted with the highest natural frequencies. From the experimental and numerical results, the hemp composite plate that gave the best results is plate 4. When designing structures for spacecraft or aircraft, usually the material with the least deflection, highest strength, and lightest mass is most desired. The second section of the project was an application to better understand the behavior of hemp composite plates. The door hinges provided better results than previous experiments because they did not alter the function of the hemp composite plates.

VIII. Appendix

This appendix summarizes the code and acknowledgements that relate to the creation of this report.

A. Matlab Code

```
%% Senior project
clear all
close all
clc

%% Excel File to Matlab

A=xlsread('Specimen_RawData_1.xlsx');
B=xlsread('Specimen_RawData_2.xlsx');
C=xlsread('Specimen_RawData_3.xlsx');
D=xlsread('Specimen_RawData_4.xlsx');

Ts1=(A(1:576,5));
Ttau1=(A(1:576,4))/100;

Ts2=(B(1:1280,5));
Ttau2=(B(1:1280,4))/100;

Ts3=(C(1:1370,5));
Ttau3=(C(1:1370,4))/100;

Ts4=(D(1:1735,5));
Ttau4=(D(1:1735,4))/100;

figure(1)
plot(Ttau1,Ts1,'b')
hold on
plot(Ttau2,Ts2,'g')
hold on
plot(Ttau3,Ts3,'k')
hold on
plot(Ttau4,Ts4,'r')
title('Stress-Strain Curve for Hemp Composite Hinged Plates')
xlabel('Strain (in/in)')
ylabel('Stress (ksi)')
legend('Specimen 1','Specimen 2','Specimen 3','Specimen 4')
```

B. Acknowledgements

Acknowledgements to Terry Muy for aiding author, Alma Melendez in creating this report and for her help during experimental results and manufacturing. Also, special thanks to Gabriel Sanchez for teaching and assisting the author and Terry Muy how to use the machines in the Cal Poly aerospace structures composites laboratory.

IX. References

[1]Malatkar, Pramod."Nonlinear Vibrations of Cantilever Beams and Plates."Diss. Virginia Polytechnic Institute and State University, 2003.Web.<http://scholar.lib.vt.edu/theses/available/etd-07152003 164905/unrestricted/Thesis.pdf>.

[2]Gallagher, R.H. "Buckling Strength of Structural Plates." H.P. Adam, R.R. Meyer, M.F. Card, W.J. Crichlow, and R.E. Hubka: Springfield, Virginia, National Technical Information Service. 1971. Web. 22 Oct. 2011. <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19710023855_1971023855.pdf>.

[3]"Natural Frequency and Resonance."N.p., n.d. Web. 22 Oct 2011. <http://www.cs.wright.edu/~jslater/SDTCOutreachWebsite/nat_frequency.htm>.

[4] Cooperative Research Centre for Advanced Composite Structures Ltd., *Putting it together the science and technology of composite materials.* , Australian Academy of Science., November 2000

[5]Mc Laren, Warren."Hempline Automotive Composites. *"Tree Hugger*.N.p., 2012. Web. 12 Mar 2012. <http://www.treehugger.com/green-architecture/hempline-automotive-composites.html>.