Use of Bio-Composites for a Milling Machine Table

Jonathan Shakhmoroff, B.S, Damian Gaona, B.S
Vaughn College of Aeronautics and Technology, United St*ates, shakhmoroff@yahoo.com, gaona.damian@gmail.com*

Mentor: Yougashwar Budhoo, PhD
Vaughn College of Aeronautics and Technology, United States, yougashwar.budhoo@vaughn.edu

Abstract– Milling machines are widely used in the machining industry and use a rotary cutter to remove material from a stock piece of material in order to create a finished and fully dimensioned product. This running machine, along with the process of removing material from a workpiece, causes several types of vibrations in the system, which can cause error in obtaining the required tolerances provided by the designer. An efficient solution is to replace the machining table, but finding the proper material is difficult. Steel is the current standard but does not sufficiently reduce the vibrations, so other materials, such as tungsten and carbon-epoxy composites, were considered. Tungsten is far too expensive and heavy to use and replace, making it inefficient. Carbon-epoxy and glass-epoxy composites prove to be excellent dampers due to the friction between strands, but recycling and manufacturing composites can be expensive and potentially bad for the environment if not done properly. The objective of this project is to create a bio-composite which will both provide damping to the system and be eco-friendly. Natural flax fibers were chosen alongside an organic epoxy to create the composite material, due to their availability and mechanical properties. The flax-epoxy bio-composite was tested against aluminum, steel, and glass-epoxy. It proved to be a more effective damper than aluminum and steel due to its higher damping ratio and low density, but failed to surpass glass-epoxy due to the thickness of the flax fabric. In terms of damping ratio per unit density, flax-epoxy comes close to glass-epoxy and may even surpass it with thinner plies.

Keywords: bio-composite, composite material, damping ratio, milling machine, vibration.

I. INTRODUCTION

In several industries, such as the construction, automotive, and aerospace industries, precision machining is extremely important. The Boeing 747-400, for example, has 6 million parts which all need to fit together properly in order for the aircraft to function. Having a component which has improper dimensions can cause problems, ranging from inefficiency to the safety of the passengers on board the aircraft.

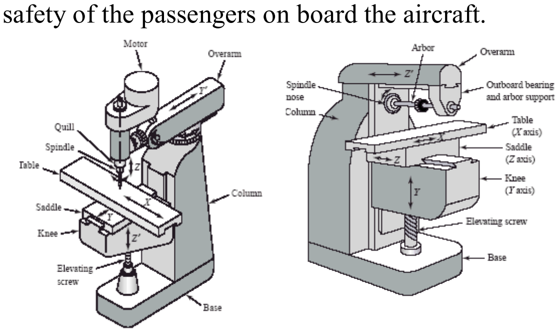

Figure 1 Different milling machines

Digital Object Identifier (DOI): http://dx.doi.org/10.18687/LACCEI2016.1.2.003
ISBN: 978-0-98228996-9-3
ISSN: 2414-6390

Computer Numerical Control (CNC) milling machines are highly used in these industries to process a variety of complex parts with the goal of achieving maximum precision. A milling machine, as seen in (Figure 1), uses the application of a circular-type tool with multiple teeth or cutting edges that remove material from a workpiece, such as steel.

The milling machine's motor running and the tool removing material from the workpiece cause several vibrations. These vibrations may cause dimensional errors in the final product, making it difficult to stay within tolerance specifications, increase machining time, and can increase chatter which will reduce the life of the tool [1] [4]. During the machining of tools, the drawings present different geometric dimensions and tolerances to present and prevent any critical defects. When tight tolerances are needed, the cost of manufacturing goes up due to the increase in time and effort.

II. VIBRATIONS & DAMPING

There are three types of vibration that cause these issues in machining: 1) forced; 2) self-excited; and 3) transient (free) vibrations. Self-excited vibrations are caused by tool chatter and can be fixed by reducing the speed that the tool is fed to the workpiece, or using special tools made to reduce these vibrations. Forced vibrations are caused by unbalanced rotating masses, irregular tool engagement, or vibration from nearby machines and can be transferred to the workpiece via the base of the machine.

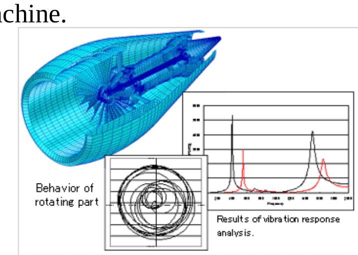

Figure 2 – Engine vibration produced by rotatory turbine.

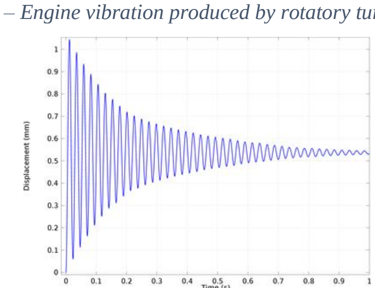

Figure 3: Free damping vibration cycles.

Transient (free) vibrations are caused by tool engagement and general machine vibration and are transferred to the part via the milling machine base. One past solution was to use a tungsten table which is extremely expensive and heavy, making it difficult to replace when damaged. Another past solution was the use of active vibration dampers, which require sensors to be set up and constantly need to be adjusted and which can also be very time consuming.

III. DESCRIPTION OF PROPOSED SOLUTION

In order to reduce the vibrations, the traditionally used steel table will be replaced with one made from bio-composites. Composites naturally have a higher damping coefficient than steel, due to the friction and resistance between fibers and themselves also fibers and the composite matrix resin [2]. Damping is often used to reduce vibrations by dissipating the energy which restricts the oscillations. In order to reduce the vibration of the part being machined, a damper must be placed between the part and the rest of the machine. A natural composite material is made by combining two or more natural materials in order to produce a material that is superior to its sub-materials.

The bio-composite will be manufactured via wet hand layup which involves laying up each layer of the material and saturating in it resin. Strain gauges will be mounted to each specimen in order for them to be tested. Each specimen will be tested for its damping ratio, using an apparatus [6] containing a breadboard with modified Wheatstone bridge, an oscilloscope, and a power supply. The new flax-epoxy bio-composite material will also be tested for other mechanical properties via tensile testing.

IV. PROJECT OBJECTIVE

For our senior degree project we will:

A. Manufacture a bio-composite material via wet hand layup.

B. Test the damping properties of the new bio-composite material along with other competing materials using an apparatus created by the previous graduating class.

C. Perform tensile testing on the new bio-composite to obtain more mechanical properties.

D. Evaluate the viability of flax-epoxy bio-composite against other material.

To create the flax-epoxy bio-composite, the material was cut into plies of the same size. The plies were stacked one at a time and saturated in the two-part bio-resin. After the cure and post-cure cycles, coupons were cut from the panel to American Society of Testing and Measurements (ASTM) coupon size. In order to test the materials for damping properties, strain gauges were mounted to the material coupons and connected to a circuit, power supply, and oscilloscope. The material was placed in a vice, given an initial deflection, and the data was collected as the material came to a stop. For tensile testing, each specimen was mounted to a tensile testing machine with sandpaper used as tabs, and results were recorded.

V. APPLICATIONS

If the new bio-composite proves to be a suitable replacement, it will reduce the time required to machine a part, due to the reduction in vibrations. The milling machine will be able to remove material at a faster rate due to the delay of the point at which chatter becomes an issue. The milling machine will also have an easier time staying within tolerance specifications. Replacing the milling machines' base with this material may increase the damping of vibrations in the workpiece, due to the higher volume of material being replaced.

Another benefit of using the flax-epoxy bio-composite is its eco-friendly advantages. After their initial use, thermoplastics tend to be chopped up and then reused for non-structural purposes. After that, they get sent to a landfill where they do not degrade; or they get sent to an incinerator at which time they release harmful byproducts. Thermosets are similar to thermoplastics in that they both don't degrade, but they differ because the resin can't be reshaped by heating. Therefore, thermoset composites must go through an expensive process of removing the resin from the fibers with a chance that the fibers will burn and/or lose their strength.

The Biotex flax fibers are a product 100% made from plant based fibers. These fibers are safe for the environment and are also a renewable resource. The Super Sap One bio-based epoxy resin from Entropy Resins is a USDA certified bio-based product. It has been tested using ASTM D6866 standards for the testing of bio-based content and resulted in a 37% bio-based content. Entropy Resins also utilize green chemistry in creating the epoxy, which is the practice of designing a product that minimizes the use and generation of hazardous substances. Additionally, unlike the regular petroleum based carbon used in epoxies, Super Sap One uses a renewable plant-based carbon which further lessens its impact on the environment.

Other uses for the flax-epoxy bio-composite include:

- Handlebars for hand-held machinery such as jackhammers
- Dampers for bridges
- Engine mounts for cars

Figure 4 – Applications of Carbon Fiber Composite Materials

VI. MANUFACTURE OF COMPOSITE

The flax fiber fabric was purchased as a 60” x 40” sheet. The weave style is a 2x2 twill with a weight of 1.96 Pa. The 2x2 twill weave style means that there are two fibers going over and two going under to create the weave. The resin used is a two-part system with an epoxy and hardener. It is necessary to mix the two using a specific ratio and using it within a certain time frame, due to a limited pot-life. To create the bio-composite material, the sheet of the flax material was cut into eight 406.4mm x 355.6mm plies (Figure 5). The epoxy and hardener were mixed with a 100:43 ratio (Figure 6). The flax plies were placed on a steel bed one at a time; and each layer was saturated in resin using a roller and brush (Figure 7). A finned roller was used on each layer to remove trapped air (Figure 8). The material was then vacuum bagged (Figure 9) and left to cure for 24 hours at room temperature (77°F) and then placed in the oven without a bag for a 2-hour post cure at 120°F (Figure 10). The final cured panel was then cut into 304.8mm x 25.4mm coupons for testing.

Manufacturing steps for the flax-epoxy bio-composite

Figure 5 - Cut plies

Figure 6 - Mixing two-part bio-resin

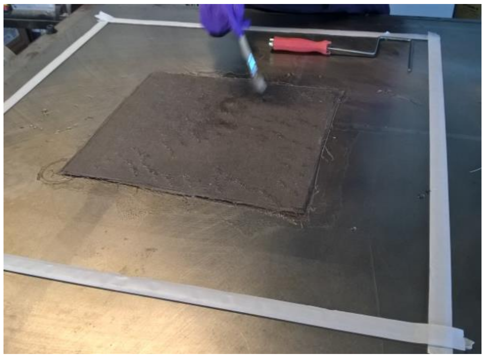

Figure 7 - Laying out plies and saturating them in resin

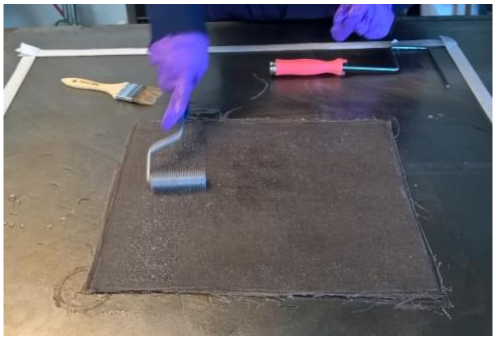

Figure 8 - Removing air with finned roller

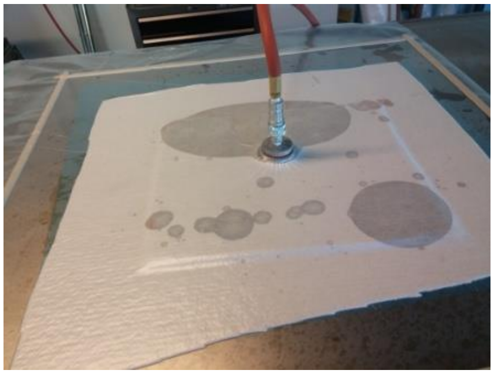

Figure 9 - Vacuum bagging composite for 24 hour cure cycle

Figure 10 - Post cure in oven at 120°F for two hours

VII. STRAIN GAGE

In order to conduct the damping tests, strain gauges are needed to obtain analog data produced by strain. Strain is the deformation of a solid due to stress. As the specimen deforms in a certain direction, the strain gauge mounted to the specimen will deform as well. Each strain gauge is designed with a certain electrical resistance; and as it deforms, the resistance changes. To install the strain gauges, a conditioner was applied to the surface and then sanded with a 320-grit silicon-carbide paper (Figure 11). Then the surface was wiped clean. The same was done again with a 400-grit silicon-carbide paper (Figure 12) to further smoothen the surface. A neutralizer (Figure 13) was then applied to the surface, scrubbed with a cotton-tipped applicator, and then wiped clean. The strain gauge and solder terminal were placed on the surface with a tweezer and then tapped down (Figure 14). The tape was lifted with the gauge and terminal still attached to it. A bond catalyst was applied to the back of the gauge and terminal and the bond adhesive was applied to the material surface. The tape was placed back to its original position and a thumb was firmly placed over it to ensure proper adhesive polymerization due to body heat from the thumb. The tape was slowly removed and wires were soldered properly (Figures 15 and 16).

Steps for mounting strain gauge

Figure 11 - Surface after conditioner and 320-grit sandpaper

Figure 12 - Surface after conditioner and 400-grit sandpaper

Figure 13 - Neutralizer applied with cotton swab

Figure 14 - Bonding catalyst and adhesive with strain gauge and terminal prepped on glass-epoxy coupon

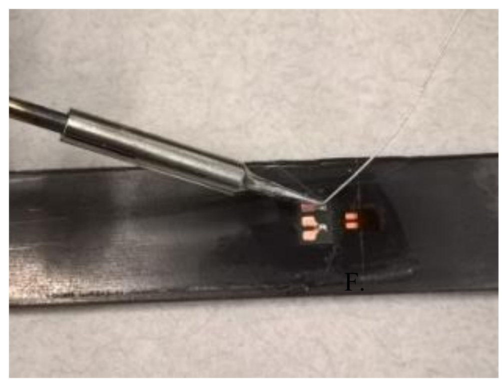

Figure 15 - Soldering strain gauge to terminal

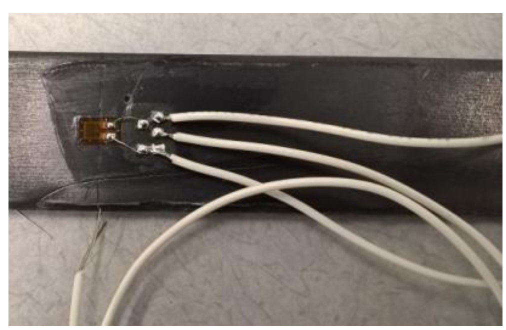

Figure 16 - Fully soldered steel coupon.

VIII. DAMPING TEST

Each material coupon (Figure 17) is placed in a vice (Figure 18) for testing. A breadboard (Figure 20) is a board used to make an experimental model of an electric circuit and is used to create the modified Wheatstone bridge with 360Ω resistors. The end of the specimen is deflected and released and the data is recorded on the oscilloscope. The strain gauge is connected to the apparatus created by the previous graduating class. This includes a power supply, oscilloscope, and breadboard with a modified Wheatstone bridge configuration (Figure 19). A power supply (Figure 21) is an electronic device that produces a user controlled voltage to an electric load and is used to supply the voltage that would ultimately be used to produce results. An oscilloscope (Figure 22) is a type of electronic testing instrument that displays its observations of signal changes over time, such as voltage, and is used to produce the raw data. Each material is tested six times to ensure accuracy.

Steps and apparatuses for conducting damping testing

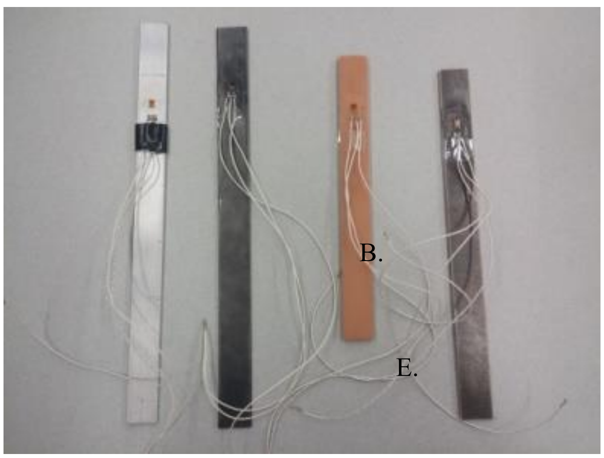

Figure 17 - Specimens with mounted strain gauges

Figure 18 - Clamped flax-epoxy specimen

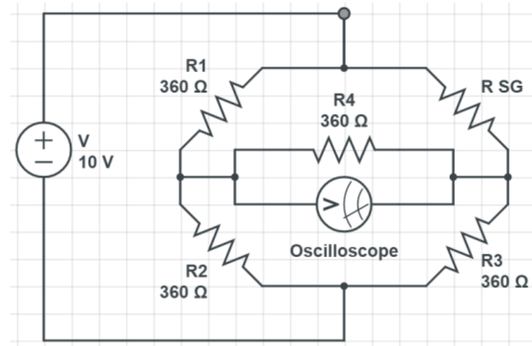

Figure 19 - Modified Wheatstone bridge circuit used for testing

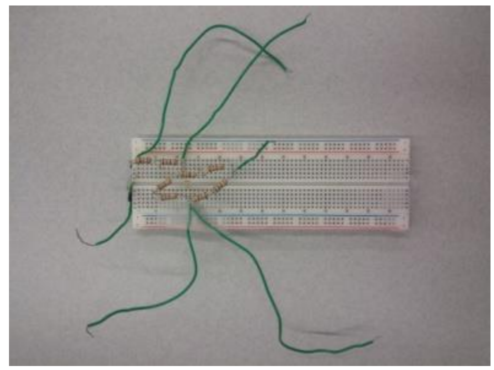

Figure 20 - Breadboard with modified Wheatstone bridge circuit

Figure 21 - Power supply unit

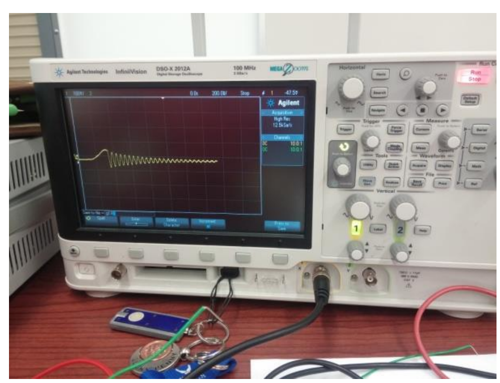

Figure 22 - Oscilloscope with graph for the oscillation of the flax-epoxy composite

IX. TENSILE TESTING

Tensile testing was conducted on four bio-composite coupons having average dimensions of 304.8mm x 25.4mm x 4.1656mm (close to ASTM standards of 304.mm x 25.4mm x 6.35mm). 100-grit sandpaper was placed on each end of the coupon to prevent slippage and to ensure that the coupon fails properly and not due to the damage from the vice. An extensometer was mounted on the specimen (Figure 23 left) in order to obtain more accurate data than the machine and was then removed in the middle of testing to prevent it from breaking. The material coupon was pulled until after it failed (Figure 23 right) and the data was recorded (Figure 24).

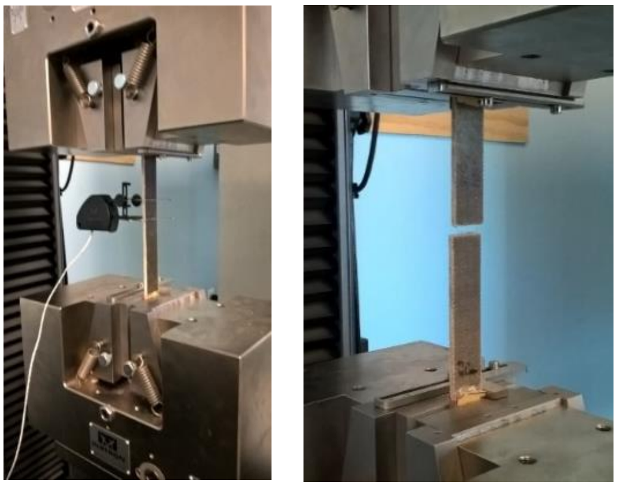

Figure 23 - Flax-epoxy coupon in tensile testing machine with extensometer mounted to it (left), Flax-epoxy coupon after fracture (right)

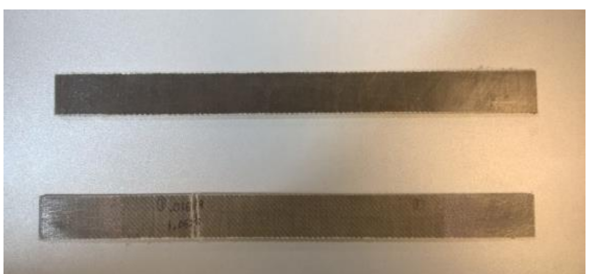

Figure 24 - Comparison of tensile tested coupon (bottom) to untested coupon (top)

X. TEAM MEMBERS AND RESPONSIBILITIES

Teamwork:

- Research fiber and resin materials that will be used and advantages or differences from other bio-composite materials that are available.
- Completion of reports needed to present the progress of the project. Including the organization of all the data and information relevant for the evaluation of the project's goals.
- Hand layup and manufacturing of Flax fiber composite at CPC facility.
- Collection of vibration test's data from the oscilloscope.
- Evaluation of the data collected from tensile and vibration tests to define and obtain all of the mechanical properties desired to support the conclusions proposed.

Individual:

Damian Gaona

- Responsible for purchasing and take charge of materials and equipment necessary to be used for the completion of the project.
- Responsible to research for technology or data that will assist in the improvement of the acquisition of the data, or the material properties.

Jonathan Shakhmoroff

- Responsible for checking all documents before submitted.
- Interpreter between team and CPC representatives for the usage of the company facility for the fabrication of the Flax fiber Bio-composite material.
- Conducted the tensile test at CPC facility with the assistance of experience staff, and collected the data to be evaluated.

XI. MATHEMATICAL FORMULATION

For obtaining the damping ratio, ζ [5]:

$$\delta = \frac{1}{\mathrm{n}} \ln\left(\frac{\mathrm{x}_1}{\mathrm{x}_{(\mathrm{n}+1)}}\right) \qquad (1)$$

$$\zeta = \frac{\delta}{\sqrt{(2\pi)^2 + \delta^2}} \qquad (2)$$

Where:

$\delta = Logarithmic\ Decrement$

$n = Number\ of\ cycles\ used\ for\ obtaining\ data$

$x = Amplitude\ value\ at\ corresponding\ cycle\ number$

Properties obtained from stress-strain curve:

Young's Modulus or Modulus of Elasticity, E, define the relationship between stress and strain and can be defined as [8]:

$$E = \frac{\Delta\sigma}{\Delta\varepsilon}, Pa \qquad (3)$$

Modulus of Resilience, Ur, is the maximum energy that can be absorbed per unit volume before permanent deformation and can be defined as [8]:

$$U_r = \int_0^{\varepsilon_y} \sigma\, d\varepsilon, \frac{N*m}{m^3} \qquad (4)$$

Modulus of Toughness, Ut, is the maximum energy that can be absorbed per unit volume before fracturing and can be defined as [8]:

$$U_t = \int_0^{\varepsilon_f} \sigma\, d\varepsilon, \frac{N*m}{m^3} \qquad (5)$$

Where:

$\sigma = Stress,\ \ Pa$

$\varepsilon = Strain,\ \ m/m$

XII. ANALYSIS

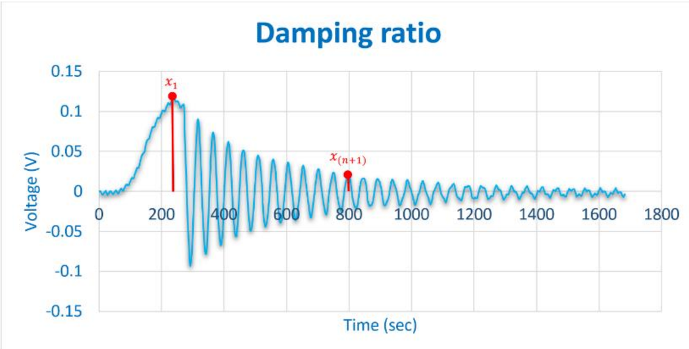

Figure 25 - Voltage vs. time of flax-epoxy specimen

Utilizing (Figure 25) and Eq.'s 1 and 2, an example of how is solved the damping ratio is presented:

$x_1 = 0.087106$

$x_{(n+1)} = 0.019147$

$n = 11$

$$\delta = \frac{1}{11}\ln\left(\frac{0.087106}{0.019147}\right) = 0.137725$$

$$\zeta = \frac{0.137725}{\sqrt{(2\pi)^2 + (0.137725\ )^2}} = 0.021914$$

Using Excel, these calculations were conducted 6 times per specimen and the average was taken for each to obtain the final results.

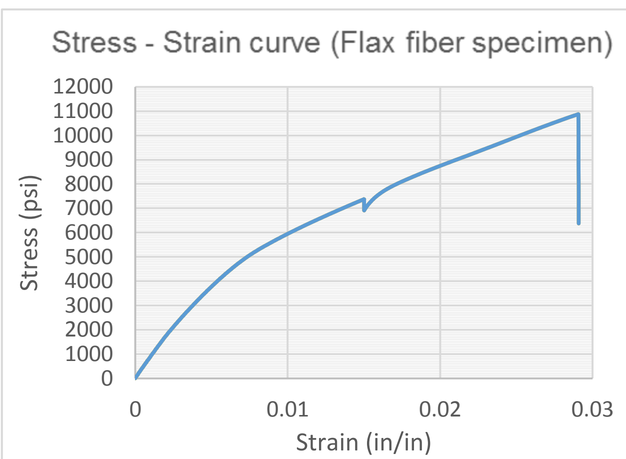

Figure 26 - Stress-strain curve of flax-epoxy specimen

The slight drop in the middle is from the removal of the extensometer and the tensile testing machine taking over the data readings.

The elastic modulus was obtained using the Eq. 3 and the data obtained from (Figure 26):

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} = \frac{3857.466 - 407.516}{0.005 - 0.000} = 0.73\ Msi\ (5.050 * 10^9\ Pa)$$

The yield strength was obtained by creating a line parallel to the initial slope of the curve and offsetting it by 0.02% on the x-axis. This resulted in:

$$\sigma_y = 5400\ psi\ (37.23 * 10^6\ Pa)$$

The ultimate strength and failure strain was obtained via the final data point on the stress strain curve and resulted in:

$$\sigma_{ult} = 10872.62\ psi\ (74.96 * 10^6\ Pa)$$

$$\varepsilon_f = 0.02909\frac{in}{in}\left(\frac{m}{m}\right)$$

The modulus of resilience was obtained using Eq. 4 by integrating the equation for the stress-strain curve obtained via Excel:

$$U_r = \int_0^{0.00831} (-3 * 10^7x^2\ +\ 913402x\ +\ 25.182)\,dx$$

$$U_r = 26.0087\frac{lb * in}{in^3}$$

The modulus of toughness was obtained using Eq. 5 by integrating the equation for stress-strain curve obtained via Excel:

$$U_t = \int_0^{0.02909} (4 * 10^8x^3\ -\ 3 * 10^7x^2\ +\ 771002x\ +\ 357.63)dx$$

$$U_t = 162.068\frac{lb * in}{in^3}\ (11.17 * 10^6 Pa)$$

XIII. RESULTS & DISCUSSION

Tabulating the results for damping testing:

Table 1 - Average results for damping ratio for the four materials tested

Specimen	Average Damping Ratio, ζ
Aluminum 6061-T6	0.01149259
Steel A36	0.015664265
Glass-Epoxy Fiber	0.039246422
Flax-Epoxy Fiber	0.022531113

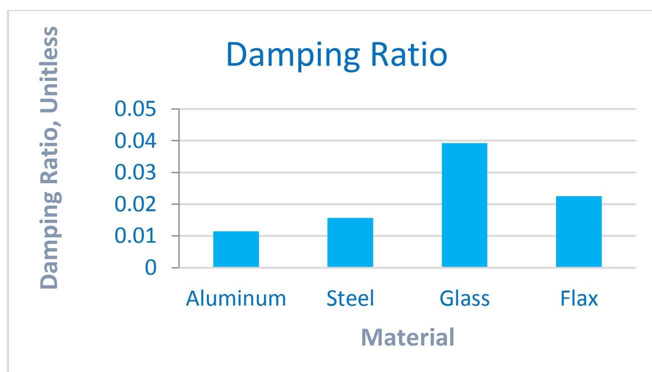

Figure 27 - Bar graph comparison of the damping ratio values

Table 1 and (Figure 27) presents that the flax-epoxy is a better damper than both aluminum and steel, but not the glass-epoxy.

Table 2 - Comparison of all obtainable properties for materials used

	Aluminum 6061-T6 [7]	Steel A36 [7]	Glass-Epoxy [3]	Flax-Epoxy
Elastic Modulus (GPa)	68.94	199.95	13.79	5.05
Yield Strength (MPa)	275.79	250.28	-	37.23
Ultimate Strength (MPa)	310.26	475.74	427	74.96
Failure Strain (m/m)	0.12	0.2819	0.0376	0.02909
Modulus of Resilience (KPa)	-	896.32	-	179.32
Modulus of Toughness (MPa)	-	123.41	-	1.12
Tangent Modulus (GPa)	-	-	-	139.37
Logarithmic Decrement	0.0722	0.0984	0.2468	0.1416
Damping Ratio	0.0115	0.0157	0.0392	0.0225
Density (kg/m^3)	2698.79	7861.09	1754.91	1234.52

Through the comparison of material properties in Table 2, it can be seen that flax-epoxy is a poor choice as a structural component but a superb choice as a damper. Due to the flax fabric's absorption, the percent volume of resin to fiber was 72% to 28%, respectively. This caused the flax fabric to lose its tensile properties but gain compressive strength from the resin. When comparing flax-epoxy to glass-epoxy in terms of damping, the glass-epoxy may seem significantly better, but not by much in terms of damping per unit density. Weight is always an important factor when manufacturing and therefore it must be considered. While glass-epoxy results in 0.6190 per unit density, the flax-epoxy comes close with 0.5056 per unit density.

Along with its eco-friendly characteristics, the flax-epoxy bio-composite can compete with glass as a damper table for a milling machine. Since it is known that the number of plies greatly affect a composites' ability as a damper due to the friction and resistance between the plies and resin, increasing the number of plies per unit of thickness will likely increase the damping ratio of the flax-epoxy. The glass and flax composites estimate to be 156 and 49 plies per inch, respectively. While there is a small difference in damping ratio per unit density, there is a large difference in plies per inch. Using thinner plies of flax would improve its damping ratio per unit density significantly; but further experiments are needed.

Some errors in the damping testing can be contributed to the signal noise of the Wheatstone bridge, which was displayed on the oscilloscope. This made it very difficult to the zero the data obtained and therefore may result in minor errors with the damping ratio and a higher standard deviation.

XIV. Conclusion

It can be concluded that the flax-epoxy bio-composite can be a suitable replacement for the traditional steel milling machine table due to having more damping capability therefore reducing vibrations and increasing the accuracy of the milling machine. While the flax-epoxy bio-composite does not have much to show for with regards to tensile properties, these properties are not heavily relied for this application.

In the future, further research in the use of thinner plies will be sought after in an effort to increase the damping ratio. Additionally, other bio-resins and natural fibers should be tested when readily available on the market.

Acknowledgement

First and foremost, we would like to thank Dr. Y. Budhoo, Professor at Vaughn College, for sharing his vast knowledge and guiding us throughout this paper and throughout our years at Vaughn College as demonstrated in (Figure 27).

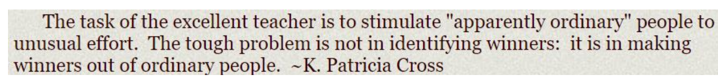
The task of the excellent teacher is to stimulate "apparently ordinary" people to unusual effort. The tough problem is not in identifying winners: it is in making winners out of ordinary people. ~K. Patricia Cross

Figure 27 - Thank you Dr. Budhoo

We also give thanks to Vaughn College Professor is Dr. Cabrera for his assistance and explanation regarding the modified Wheatstone bridge and oscilloscope used in performing the experiment.

Further appreciation goes out to the employees and proprietors of CPC (Composite Prototyping Center), SciMax Technologies, Nordan Composite Technologies, and for their advice, manufacturing and testing expertise, and financial support in making this project possible:

- Leonard Poveromo - Executive Director of CPC for financial support
- Max Gross - Principal of SciMax Technologies for engineering advice
    - Joseph Bruno – Chief Engineer of SciMax Technologies for engineering advice
- Dan Dispenze - Owner of Nordan Composites Tech. for cutting material
- Dan Dispenze Jr. - Composite Technician at Nordan for cutting material
- Mark Schmiemann - Sr. Technician at Nordan for helping manufacture and curing material
- Michael Murphy - Retlif Test Engineer and Director of Operations at CPC for tensile testing composite coupons

BIBLIOGRAPHY

[1] Rahman, M., Mansur, A. and Karim, B. ―Non-conventional material for machine tool structures [J]. JISM International Journal, Series C, 44(1), 1–11, 2015.

[2] Nashif, A. D, Jones, D. I. G. and Henderson, J. P. “Vibration Damping”, Wiley, New York, (1985), 2015.

[3] Y. Budhoo, F. Delale, B. Liaw. Temperature Effect on Tensile Testing of Hybrid and Non-Hybrid Composites. Thesis. SEM 2011 Annual Conference & Exposition on Experimental and Applied Mechanics, 2011.

[4] S. Syath Abuthakeer, P.V. Mohanram, G. Mohan kumar, “Structural redesigning of a CNC lathe bed to improve its static and dynamic characteristics”, International journal of Engineering, 2, pp. 389-394, 2015.

[5] Rao, Singiresu S. Mechanical Vibrations. 5th ed. Upper Saddle River, NJ: Prentice Hall, 2011. Print.

[6] M. Ayoub, S. Han, C. Patel. Damping and Natural Frequency of a Cantilever Beam. Thesis. Vaughn College of Aeronautics and Technology, 2015.

[7] "Online Materials Information Resource - MatWeb." *Online Materials Information Resource - MatWeb*. N.p., n.d. Web. 11 May 2016. <http://www.matweb.com/>.

[8] Callister, William D., and David G. Rethwisch. *Materials Science and Engineering*. Hoboken, NJ: Wiley, 2011. Print.