

Modeling And Simulation of The Performance of Cocos Nucifera (COIR) In Polyurethane Composite Laminate for Vibration Damping

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Abstract—The research tends to evaluate the characteristics of machine and structure behavior to vibration sources and model a new vibration damping attenuating material using the coconut fiber for purpose of building an effective damping device for structural and dynamical systems. The relatively small differences between the expected values of the model were attributable to imperfections, in terms of fiber/matrix, adhesion and voids, in the analyzed composites. This type of modeling allows a better characterization of natural fiber composites which mechanical properties are strongly affected by the broad distribution of fiber dimensions. The proposed method is a major problem of the natural system, like the dispersion of properties, approached utilizing a more accurate semi-empirical methodology, can be useful in the design and the optimization of the processing of nature fiber reinforced composites.

Index Terms— Coir, Vibration, Polyurethane, Fiber, Strength, Structure, Absorber

I. INTRODUCTION

The Lagos state government in recent time focused on building integrity test because of the frequent cases of building collapse within the state. In Lagos state, the clear-cut demarcation of industrial facility and residential facility had been violated over the years. The interference of industrial facility equipment vibration and noise with residential building cannot be overemphasized. These include the use of reciprocating machines and industrial generators which causes vibration transmission through the ground onto building foundations. Dynamic and structural systems often encounter undesirable

vibration which could be controlled to avoid failure or breakdown and instilled the possibility increase system lifetime. It therefore becomes necessary to control the vibration emanating from such machines and or attenuating the vibration absorbed by the surrounding buildings. In recent time vibration had become a problem for concern because of the manufacture of machine with increasing speed of operation. It then become a challenge for researchers to design and implement effective and efficient vibration control method aimed at reducing the transmission of vibration from machines and structures (Kuku et al., 2024a). The pattern towards lightweight and ceaseless designs implies that vibrations are sent promptly.

Damping can be defined as the impact inside or upon an oscillatory framework that lessens, limiting or forestalling its motions. In actual frameworks, damping is delivered by processes which disseminates the energy put away in the wavering. Damping not founded on energy misfortune can be significant in other swaying frameworks. The damping proportion is a dimensionless measure depicting how motions in a framework rot after an aggravation. Numerous frameworks show oscillatory conduct when upset from their situation of static harmony. The conduct of wavering frameworks is frequently important in an assorted scope of disciplines which incorporate underlying designing, synthetic designing, mechanical designing, control designing, and electrical designing. The actual amount that is wavering changes extraordinarily, and might be influencing structure in the breeze that are tall, or electric engine's speed, however a balance, or non-dimensional methodology

can be advantageous in portraying normal parts of conduct. Composite materials have successfully been used for the creation of engineering devices because of their anisotropic properties, stiffness and strength characteristics. The composite material is the combination of more than one material with superimposed properties of the individual component material.

There are various vibration control approaches which could be passive, semi-active and active control approaches. The passive vibration control involves the addition of material with sufficient stiffness and damping index to the vibrating system. This reduces the dynamic response of the machine and also provide suitable excitation frequencies operating condition for the vibrating system. The passive control involves using devices which could be the incorporation of fluidic or elastomeric materials. The active control method is a closed loop feedback system which tends to remove mechanical energy in heat form (Liao *et al*, 2011). Liao *et al*, 2011 designed a magnetorheological elastomer active tuned vibration absorber with attached voice coil for purpose of improving the performance of the control system.

The selection of control system for vibration often required dynamic analysis of vibrating systems. Only the most significant features are considered in the analysis in order to predict the system's behavior under specific condition, the features are derivation of the governing equations, mathematical modeling, solution of the equations and interpretation of the results. An analogous scheme for the case of damped systems unlikely, the vibration control problems, cannot be formulated as a system of linear equation s problem. The numerical optimization has been studies extensively during the past few decades. The optimization problems studied from the perceptive of non-linear optimizing problems in often troublesome than solving linear equations mostly, when the numbers of design variables is high, the degree of numerical difficulty increases.

Many theoretical models have been investigated to estimate the stability threshold speed above which no stable operation is possible to validate models, experimental methods are necessary. Non-contact excitation and measurement techniques are needed because the system is rotating. Liu and Coppola, 2010 focused on the optimal designed damped dynamic vibration absorber for damped primary systems. Two

numerical approaches were employed. The first approach was used to solve the set of nonlinear while the second approach was used to minimize the objective subject to a set of constrained. Two models develop for purpose of similarities optimum vibration absorption system. The model the of discrepancy between numerical solutions and the analytical solutions. The design of control systems and devices had consistent assisted in the vibration control of machinery operation. The primary objective of any vibration control system or unit is to be able to dissipate energy arising from the machine vibration towards reducing the displacement amplitude.

Viscoelastic damping material composite had been used successfully for the gradual dissipation of wave energy (Zhou *et al*. 2019). The experimental results demonstrated that perforated viscoelastic damping material has good performance in engineering practice for damping operation with high and medium frequency range energy dissipation characteristics. The results were numerically and theoretically validated by analyzing the accuracy of the numerical and theoretical results using the experimental data.

Kim and Kang, 2013 attempted a study on efficient floor vibration analysis of shear wall finite element analysis method is used dues to its increase in accuracy as the number of nodes increases. The entire building structure where the vibration occurs is subdivide into a finer mesh for accurate analysis, also in order to reduce the computational time the number of degrees of freedom was significantly increased. In this study, the analytical method eliminates all the degrees of freedom except for those related with translation perpendicular to the walls or slabs by matrix condensation, was proposed for the efficient floor vibration analysis of a shear wall building structure. Momtaz *et al*. 2017 examined wind-initiated vibrations in tall structures with tuned mass dampers considering vortices impacts made by the liquid stream and the control of this phenomenon. To this end, the administering conditions of the construction, the liquid stream and the tuned mass damper are first presented, and their coefficient esteems are separated by the attributes of ACT high rise in Japan. Then, at that point, these three coupled conditions are settled utilizing a program coded in MATLAB. After approval of the outcomes, the impacts of wind loads are examined and considered concerning the impacts

of vortices and the utilization of tuned mass damper, and are contrasted and the consequences of the state where no vortices are thought of. For the most part, the consequences of this review call attention to the meaning of vibrations brought about by vortices in development of designing constructions just as the suitable execution of a tuned mass damper in diminishing motions in tall buildings.

Coconut Coir is a natural fibre extracted from husk of coconut. The coir is found between the hard internal shell of the coconut and its outer coat and had been successfully used for the development of floor mats, brushes, insulation, packages and had served as reinforcement materials in thermo-set and thermoplastic production among some other application (Joseph *et al.* 1996). Using natural fibres, e.g., coconut fibre as reinforced composite in recent time is a focus of discuss in replacing the inorganic reinforcement (Murali and Mohana, 2007; Ismail *et al.* 2010). Naveen *et al.* 2013 determines the mechanical (dynamic and static) properties of a proposed combined polymer composite which consist of a polyester matrix and coconut fibres. The influence of fibres volume on the mechanical properties was also evaluated in Kuku *et al.*, 2024b. Tensile test was done to know the material's strength by using universal Testing Machine. The results indicates that the tensile modulus changes with the fiber coconut. Bujang *et al.* 2007 carried out the study to determine the mechanical properties and dynamic characteristics, combined polymer composite which consists of a polyester matrix and natural fibers. The influence of fibres volume on the mechanical properties and dynamic characteristic of the composites was evaluated. Naveen *et al.* 2013 investigation was based on composite material has been in use for centuries. It began with natural fibres, and has been assessed to be economically and environmentally useful materials owing to their biodegradability and renewable features. The increasing interest in cosmetic, automotive, and plastic lumber application has really skyrocketed demands for natural fibres reinforced composite and hence, interest in coir fiber due to its durability, water- proof ability and resistant damage by salt water and microbial action. The study dealt with the and performance and characterization of natural fiber reinforced composite by analyzing the effects of fiber volume, length on composite mechanical properties and its dynamic characteristics.

Verma *et al.* 2013 discussed epoxy resins characteristics by the presence of one 1, 2- epoxide group per molecule. Reinforcement was the major reason to enhance the mechanical properties of the resin system and ceramic matrix is the ceramic materials of inorganic, non- metallic materials made from compounds of a metal and a non- metal, formed by the action of heating and subsequent cooling. The classes of components are Particulate Composites This is composed of particles suspended in a mixture and it may be spherical, cubic, tetragonal, platelet or other shape, but it's approximately equal. Flake and filled/skeletal are the two subclasses of particulate.

The areas of application of composites have grown rapidly over the years and even found new markets. They've proven their worth in weight saving, the current challenge is to make them durable and cool effective. This has resulted in many new techniques currently being used in the industry in areas like the transport sector, composite device to reduce, even support beam of bridges, and repair of seismic activity. While composite has vast applications, its selection will depend on factor such as working life, lifetime requirement, complexity of product, shape, number of items to be produced, savings in terms of cost and experience and skill of designer to trap optimum skill of the composite. Gelfuso *et al.* 2013 researched on polymers plus coconut fiber composites were made by injection processing and mechanically by tensile and dynamic testing. The young's modulus parameters obtained was found to reduce with the load applied on the fiber. The elastic modulus values were obtained by the half -power bend method and the stress- strain test was compared. The dynamic method used to measure the elastic modulus for coconut fiber-P composites was resulted as a non- destructive method and dependable test.

The environmental merits of natural fillers include decreased dependence on non-renewable materials sources, lower pollution and green house emission. Low cost, high toughness, corrosion resistance, low density and reduced tool wear are the merits natural fillers have trachtimal ones. However, Natural fillers have demerits like degradation by moisture, on-uniform filler sizes, poor surface adhesion, and low tensile strength. The use of natural fibre polymer composites filled with organic fillers is of great interest because it is a more intelligent way of utilizing the environmental and financial resources through

some limitation, occur regarding ductility, process ability and dimensional stability. The utilization of coconut shell fibre has opened up new avenue, both in academics as well as industries, to design a sustainable module for future use of coconut shell fibres-based composite using different matrixes has developed cost effective and ecofriendly bi-composites. The ultimate goal of utilizing the coconut shell to its full extent is far behind its projected milestone.

Zulkifli *et al.* 2010 had investigated the potential use of coconut coir for sound absorbing material. Shiney and Premlet, 2014 reveals that coir mats shows good absorption coefficient at high frequencies and also the coir mats with polyurethane foam backing improves the absorption capability of such composite. In view of this, coating the mats with fire resistant material makes it suitable for building acoustics and automobiles. The study shows that the effective combination of the coconut coir with porous layer backing could serve as an effective sound absorbing medium. Coconut coir fibre was found to have good sound absorption at higher frequencies, but less value for the lower frequencies (Yahya *et al.* 2017). This acoustic characteristic of the coconut coir gives an insight into the possibility of its use for vibration absorbing medium. In view of this it is necessary to evaluate the likely properties of the coconut coir that could be responsible for its possible use as a vibration absorbing medium. This paper therefore tends to evaluate the coconut fibre mechanical properties towards establishing a possible damping property inherent in the material. Investigating the mechanical and dynamical characteristic of coir fibre reinforced composite cannot be over emphasized as a result of its engineering application associated with its damping and stiffness characteristics combined with its rigidity (Shaik *et al.*, 2003). The volume fraction of the natural fibre has a vital effect on the composite strength where the composite strength rises proportionally with the volume fraction increment. The need for composite material development engineering application using coir could be a subtle opportunity for weight saving materials with quality durability, toughness and cost effectiveness (Nazeer, 2014). Gelfuso *et al.*, 2014 has established the possibility of the use of coconut fibre for vibration damping. The study performs dynamic test on composite based on coconut fibre-polypropylene and deduced that the increase in

fibre content reduces the Loss Factor, Loss modulus and Storage Factor. This behaviour was attributed to lower elastic modulus of the fibre.

Reis 2006, revealed the mechanical characteristics of an epoxy polymer concrete reinforced with natural fibres which were investigated to analyses the possibility of replacing the synthetic fibres. The normal fibers were coconut, sugar stick bagasse, and banana fibers are reused materials. As the regular fibers were agrarian waste, fabricating utilizing a horticultural produce turned into a monetary and intriguing choice. The explanation was to utilize the fibers as they came from nature with no sort of arrangement. Jang *et al.* 2012 focused on dynamic stiffness method used to model the device, constrained in the translational direction and to rotate. The method was stretched out and applied to the plan of a 2 level of opportunity TVA and a mathematical technique was utilized to decide the ideal measure of damping. Stephano and Galdius 2017 examined the mechanical properties effect on the behavior of hybrid composite material and tensile strength and effect on chemical test were made on the hybrid composite material containing coconut coir and nylon mat as reinforcement materials on epoxy resin matrix. The hybrid composite was prepared using hand layup technique which was very easy. The hydrophilic nature of natural fiber materials because of the presence of lignin and pectin causes adverse effects. It results in issues with adhesion with polymers and reduces the mechanical properties of the produced composite material. Chemical treatment can improve the adhesion between natural fibers and polymers. The rigidity of composite material with palm fiber treated with Sodium Hydroxide was higher than the composite example which was not exposed to any treatment.

Kumar *et al.* 2016 assessed the mechanical properties of coir fibre reinforced composites with different weight fraction of fibre. Coir fibre and epoxy polymer were used to prepare composites and experimental investigation are done on the composite with varied proportion of coir fibres and the effect of different weight fraction of coir fibre on tensile properties, impact strength and hardness property of specimens was analyzed. Conclusively, the versatility and applications of coconut fibres in different fields

discussed. Coconut fibres are reported as most ductile and energy absorbent materials. It is noted that coconut fibres have what it takes in order to be used in composites for various purposes. It is in no doubt that the Vibration control of mechanical systems by suppression or attenuation is important. Coconut fibre composite could be developed as a viscoelastic material to serve as an absorber for dynamic vibration as is been widely applied by some other viscoelastic materials. Which could be a successful approach towards beneficiation of coconut fibre as low cost and maintenance vibration attenuating material.

Polyurethane is an elastomeric polymer occurring in different format such as rubber. There are two types of polyurethane material are the polyester and the polyether. Polyurethane is widely used either as flexible polyurethane foam, rigid polyurethane foam, polyurethane ionomers, or thermoplastic polyurethane (Akindoyo *et al*, 2016). These applications are found in automotive industry, home appliances, including building and construction. The properties of polyurethane (PU) could be soft, in rubber forms or rigid thermoplastic and thermoset materials. Their application is based on their relationship between their structure and properties. The characterization and formation of polyurethane (PU) foam was discussed in Moises 2010. The polyurethane is used to produce a large number of products. Its application as fibers and elastomers should be well explored in vibration damper application; it is a versatile material. The chemistry types and synthesis of the PU of different types are well discussed in Akindoyo *et al*. 2016. The evaluation of the mechanical properties of polyurethane powder using suspension and dispersion polymerization have found application in Automobile, printing rollers solid PU plastic, seenlement, and fiber grating.

II. MATERIALS AND METHODS

2.1. Modeling and Simulation

The composite laminate was modeled using AutoCAD version 17 and the simulation work was carried out using the ANSYS commercial software version 2019. The ANSYS enabled models to be solved as quickly as possible by simply importing the geometry under investigation with the right physical and material properties associated to it, meshing it, loading and also by applying the boundary conditions to the material to

be modeled. The Model for the composite laminate in 3D is as shown in Figure 1.

Modal analysis was used to determine the dynamic properties of the composite laminate in the frequency domain by determining the mode shapes and natural frequencies. The modal analysis technique revealed the dynamic characteristics of the system under vibration excitation. The vibration characteristics such as the natural frequencies, mode shapes and the damping factor of the composite were then determined. The mode shape is the deformed shape of the system at a specific natural frequency. The focus of the modal analysis is to determine the frequency at which resonance of the vibration is likely to occur.

Harmonic analysis was used to develop the Frequency Response Function (FRF) of the natural frequencies. The frequency response is characterized by its magnitude in this case. The harmonic analysis was linked with the modal analysis for purpose of sharing data. The input of the composite was subjected to a range of frequency 815 - 824 Hz and a solution interval of 10. The amplitude of the stress and deformation responses at each frequency was recorded. The mode superposition method was applied for the analysis. The simulation was done with an input acceleration of 100 m/s^2 .

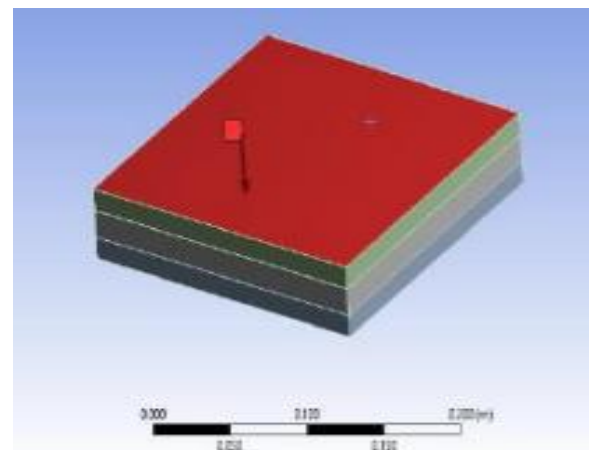


Figure 1. 3D Model for Coconut Fibre-Polyurethane Foam Composite Laminate

2.2. Preliminary processing

In the pre-processing, the specimen was modeled, and the input file stored. The part module was used to create 64 composite laminates and each subjected to harmonic loading for capacity load of 10, 20, 30, 40 and 50 kN uniformly distributed on the surface of the composite laminate.

The property selection included characterizing and doling out material and area properties to the part, every district of the deformable body must allude to a segment property which must include the material definition. In defining the section, the young modulus, Poisson's ratio and yield stress were assigned to the material part. The assembly module for the composite contains all the geometry included in the finite element module within the software.

In the step module, analysis step and output request were defined, since interaction, load and boundary condition can dependent on step. So, the analysis step to be defined before these can be specified. For the simulation static and linear perturbation were defined. For the model, boundary conditions were applied on the two ends by making sure that one end was fixed and displacement was assigned to the other end of the model to create room for movement.

2.3. System simulation

The Module here was done by creating a Job. When all the parameters involved in the model were accomplished in the Job Module we selected submit, to submit the job for analysis.

III. RESULTS AND DISCUSSION

Simulation of the Coconut fibre Composite Laminate

The result for the simulation is presented for static response and harmonic response of the composite when subjected to static loading required for the non-operating situation of the machine and dynamic loading when the machine is in operation.

3.1. Static Response

The static structural analysis indicates that the peak value for the amplitude of the composite laminate of 24.221 mm was obtained at frequency of operation of 815.7 Hz which is below the average obtained for the Lathe machine vibration measurement. This implies that the composite may be suitable as a damping material for the machine under static condition.

Figures 2 to 4 show the deformation patterns of the composite laminate under static structural analysis. The equivalent elastic strain for the composite was obtained as 0.0000249 mm/mm with maximum principal stress of 37.797 kPa and total deflection of 0.000347 mm. Whereas the elastic strain of the composite laminate is uniformly distributed (Figure

2), the maximum principal stress for the material will likely occur at the edge boundary of the composite as shown in Figure 3. The maximum deformation will occur at the midpoint of the composite. This implies that the percentage content of the coconut fibre should be concentrated at the middle portion of the composite for effective performance.

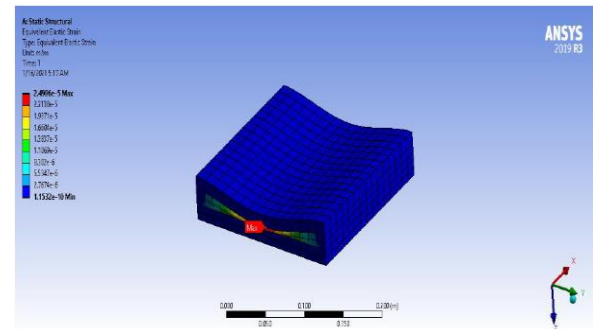


Figure 2. Static Structural Equivalent Elastic Strain for Coir-Polyurethane Laminate

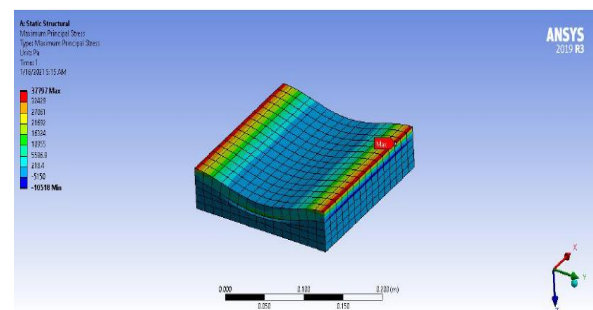


Figure 3. Static Structural Maximum Principal Stress for Coir-polyurethnae Composite Laminate.

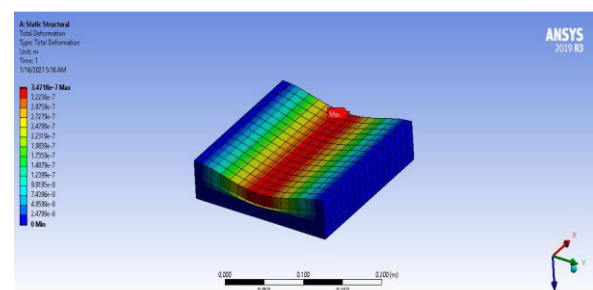
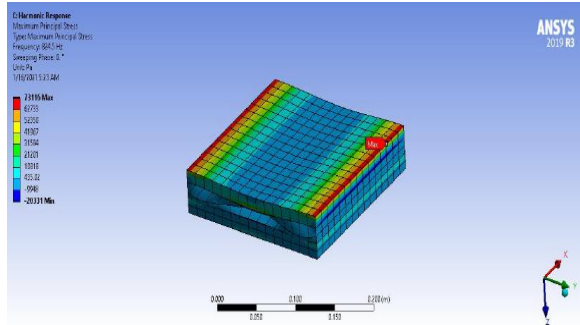


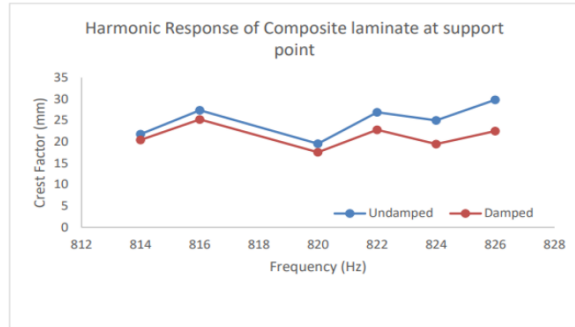
Figure 4. Static Structure Total Deformation for Coir-polyurethnae Composite Laminate.

3.2. Harmonic Response

The deformation during harmonic response analysis is minimal as shown in Figure 5a and 5b compared with the static structural analysis. This implies that the composite is likely to perform better during the machine operation.



(a)



(b)

Figure 5. Harmonic Response MPS for Coir-polyurethane Composite Laminate.

3.3 Analysis of the operating condition on the characteristics of the laminate

Compression test was used to validate the results obtained from the ANSYS workbench using the Universal Compression testing machine as discussed in Raji and Kuku et al 2024b. Table 1 shows the configuration of fiber laminates with different composition. The Maximum compressive strength obtained from ANSYS was compared to the results from the Maximum Compressive strength carried out experimentally with Universal Compression testing machine.

Figures 6 to 17 show the ANSYS maximum compressive strength of the fibre composite laminates coded C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11 and C12 respectively. It was observed that the stresses were generally maximum at the centre regions of the laminates whose surfaces were in contact with the machine plates when the upper ram is at its lowest position while the region of minimal compressive stresses was observed at the edges of the fibre laminates.

The comparison between the experimental and ANSYS results is shown in Table 1 and Figure 13 shows that the maximum compressive strength is

greatest for laminates with C1 configuration and least for the laminate with C12 configuration. The result from Figure 13 shows the experimental results are in close agreement with the finite element results. As explicit in Table 2 and figure 18. Hence, the finite element model is validated and sufficient to determine the behavior of this coconut fiber composites laminates in vibration damping.

Table 1. Configuration of fibre laminates

Mould	Coir Fibre Thickness	Polyurethane Foam Thickness	Coir Fibre Thickness	Configuration
	H ₂ (mm)	H ₂ (mm)	H ₃ (mm)	
1	5	10	5	C1
2	5	15	5	C2
3	5	20	5	C3
4	10	10	10	C4
5	10	15	10	C5
6	10	20	10	C6
7	15	10	15	C7
8	15	15	15	C8
9	15	20	15	C9
10	20	5	20	C10
11	20	10	20	C11
12	18	10	18	C12

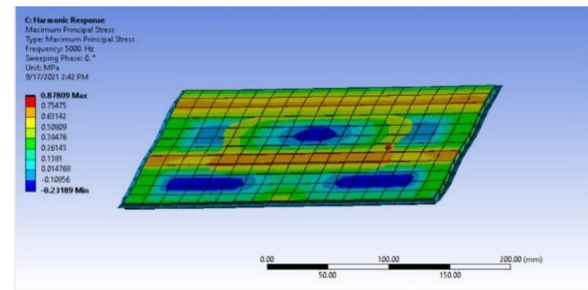


Figure 6. Maximum Compressive strength of C1 Fibre Composite laminate

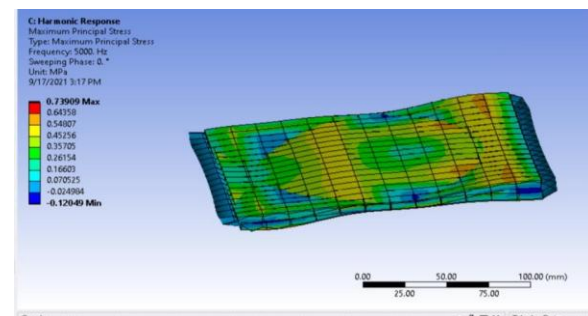


Figure 7. Maximum compressive strength of C2 Fibre Composite laminate

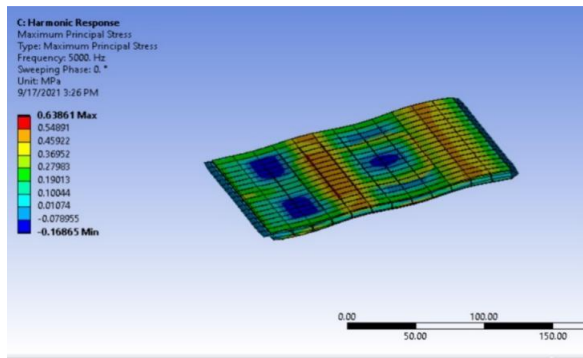


Figure 8. Maximum Compressive strength of C3 Fibre Composite laminate

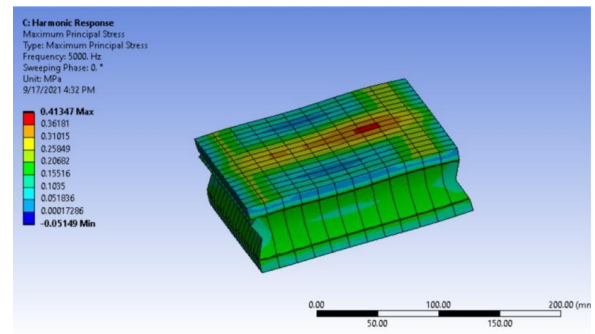


Figure 12. Maximum Compressive strength of C7 Fibre Composite laminate

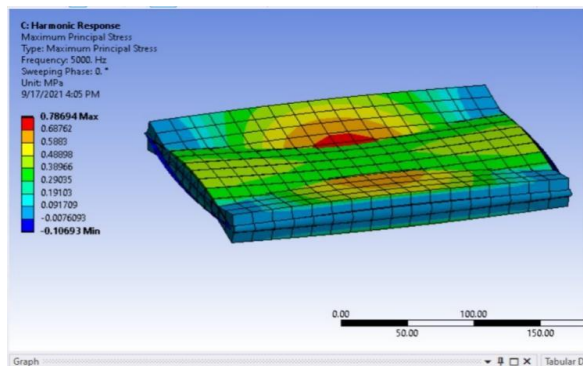


Figure 9. Maximum Compressive strength of C4 Fibre Composite laminate

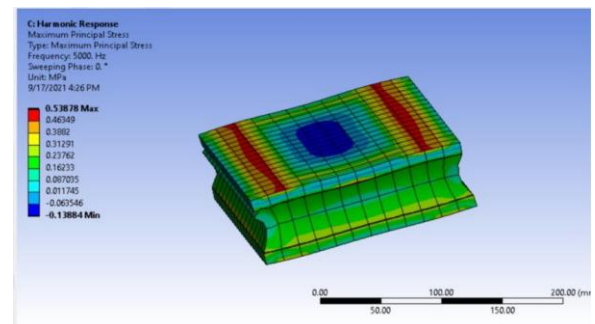


Figure 13. Maximum Compressive strength of C8 Fibre Composite laminate

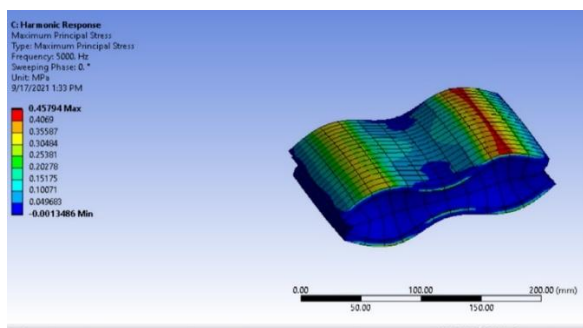


Figure 10. Maximum Compressive strength of C5 Fibre Composite laminate

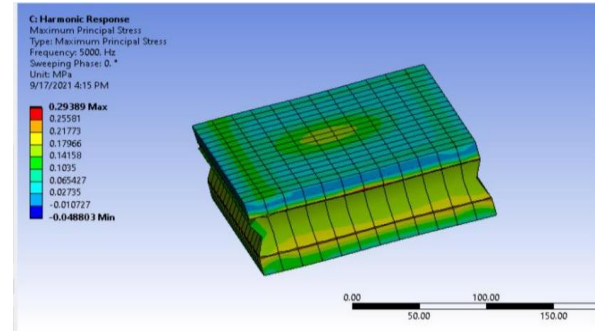


Figure 14. Maximum Compressive strength of C9 Fibre Composite laminate

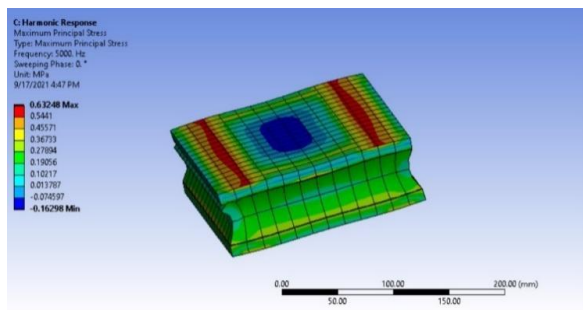


Figure 11. Maximum Compressive strength of C6 Fibre Composite laminate

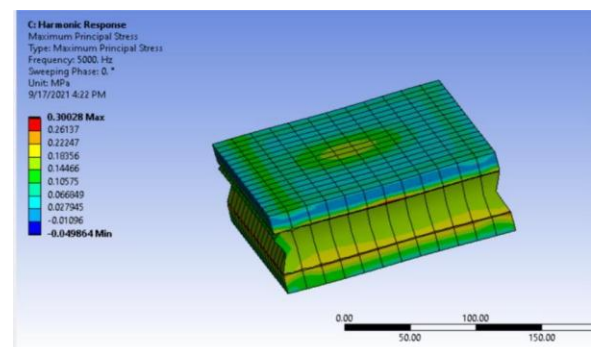


Figure 15. Maximum Compressive strength of C10 Fibre Composite laminate

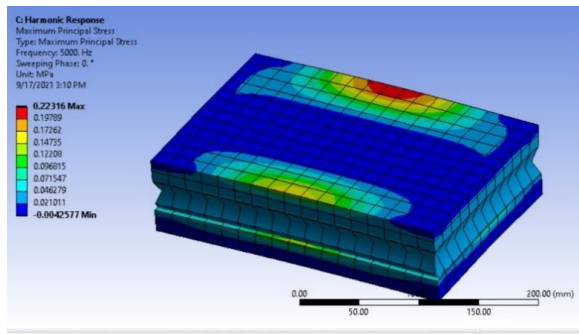


Figure 16. Maximum Compressive strength of C11 Fibre Composite laminate

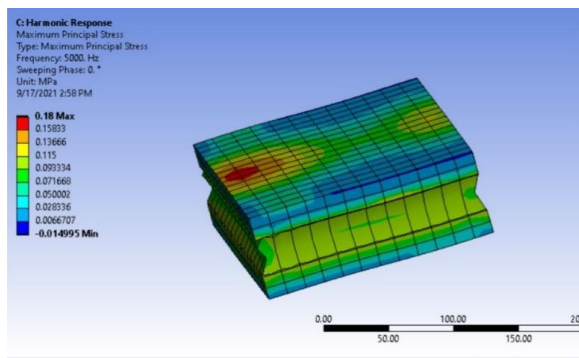


Figure 17. Compressive strength of C12 Fibre Composite laminate

Table 2: Maximum Compressive strength results from experiment and finite element.

			EXPERIMENTAL	FINITE ELEMENT
Fibre Composite Laminate Configuration	Ultimate Compressive Load (N)	Area of Surface Laminates (sq. mm)	Maximum Compressive Strength (MPa)	Maximum Compressive Strength (MPa)
C1	23000	27000	0.85185	0.8789
C2	20000	27000	0.74074	0.73909
C3	17000	27000	0.62962	0.63861
C4	18000	27000	0.66667	0.78694
C5	12000	27000	0.44444	0.45794
C6	16000	27000	0.59262	0.63248
C7	10000	27000	0.37037	0.41347
C8	14000	27000	0.51852	0.53878
C9	8000	27000	0.29630	0.29389
C10	7500	27000	0.27778	0.30028
C11	6000	27000	0.22222	0.22316
C12	5000	27000	0.18518	0.18000

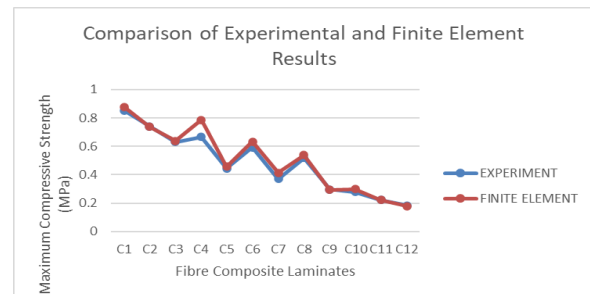


Figure 18: Comparison of Experimental and Finite Element Results

IV. CONCLUSION

Excessive vibration usually occurs in operating machines whose natural frequency amplitude coincides with the frequency of the external excitation of the machine. The vibration causes the imperfection in the production output of the machines especially finishing of the work piece which sometime might lead to chaotic machine response which causes machine failure. Such vibrations can be attenuated by coupling a properly designed vibration dumping device with inbuilt mass-spring-damper characteristic. These devices are referred to as dynamic vibration absorbers. The composite laminate of the coconut fiber- polyurethane laminate was fabricated laminate using compressive test analysis it was found to be in close agreement with simulation results and sufficient to conclude that the behavior of the laminate defined its ability to reduce the frequency excitation of dynamic and static structures. The result found that mechanical properties associate a great deal with the dynamic characteristics of the composites such as tensile strength, flexural strength, impact strength among others and are greatly influenced by the fiber lengths. Dynamic characteristics such as natural frequency can be predicted by analyzing the mechanical properties. It is clearly observed from the experiment that natural coconut coir fiber matrix is best suitable for Structural and non- Structural applications.

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