Significant Applications of Composite and Natural Materials for Vibration and Noise Control: A Review

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1 Introduction and Literature Review

Increasing environmental consciousness and demands more sustainable product has pushed the manufacture to consider the removal of traditional composite which uses synthetic fiber as reinforcement such as glass, carbon or kevlar. For this reason, the substitution of conventionally used synthetic fiber materials by natural fibers has become an emerging area of interest. Natural fibers fiber based composite have lower cost as compared to synthetic fiber; they are biodegradable and cause less pollution and minimal health hazards. These renewable materials could be used to replace new conventional composite. The use of composite materials in structural components requires better understanding of static and dynamic properties of the fiber and matrix. The dynamic properties, damping, and sound absorption are important factors in many industrial applications, especially, for automotive industry. The composite structures could improve the vibration damping since the energy dissipation of composite materials is much better than the convention structure and hence is a better alternative.

Composites reinforced with natural fiber such as sisal, jute, and kenaf have recently drawn a lot of attention from researchers due to their good mechanical properties,

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P. Verma et al. (eds.), *Advancement in Materials, Manufacturing and Energy Engineering, Vol. II*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-16-8341-1_17

light weight, environmentally friendly, and sustainability. Composite reinforced with sisal has shown potential for structural application at low economic cost [1]. Natural fiber has good potential. They have many advantages such as low density and cost and sustainability. The product derived from natural fiber reinforced composite can be reused or incinerated and do not have to be land filled as other synthetic fiber [2]. Composites reinforced with natural have better acoustic performance and vibration damping properties over synthetic fiber based composites [3, 4]. Natural fiber based composite flax-PP found widespread uses especially in the automotive sector with Polypropylene (PP) be most widely used matrix with natural fiber [5, 6].

Hadiji et al. [7] has analyzed the composite of the flax-PP, hemp-PP, kenaf-PP, and glass-PP with nonwoven fabrics and influencing factors such as type of fiber used, the volume fraction of fiber/matrix, the fiber orientation, and the porosity content, on the damping behavior of these composites is analyzed and compared with the convention glass fiber-PP composite. Free flexural vibration test is conducted with different fiber orientations and porosity (4–64%). It also shows as the porosity is increased the loss factor is also increased at 64% porosity the increase in loss factor by 108.7%. Thus porosity can play a vital role in increasing the damping property of the composite. Merotte et al. [8] has analyzed the effect of porosity content of flax-PP composite and how it affects the acoustical and mechanical properties of the composite. It explores the compaction rate during the manufacturing which directly affects the porosity and at which porosity we get the best sound absorption without sacrificing other mechanical properties. The porosity content varies from (0–70%). When the porosity is 60% the porous network is tortuous, the sound wave spread through the network due which the fiber rub against each other which eventually dissipate the energy into heat.

Mamtaz et al. [9] studied factors such as bulk density, fiber finesse, grain size, sample size thickness, and granular size in sound absorption of the composite. Fiber size can increase the sound adsorption at lower frequency levels. Authors also investigated the fibrogranular composites which have better sound absorption than conventional fiber composite, the granular size granulates of grain sizes between (0.71–1) mm and consolidated material of grain size less than 2 mm contribute higher to the flow resistivity and hence increases the sound absorption of the composite, it also states that the bulk density also increase the sound absorption of the composite in medium and high frequency range, increasing the sample thickness increases sound absorption at low frequency region but not at high frequency region. Rahman [10] studied damping mechanism which is present in composite. It shows results regarding fiber aspect ratio, volume fraction, fiber orientation, polymer material (viscoelastic nature), and effect of frequency on the damping of the composite. The increase in volume fraction of fiber increases the vibration damping in spite of the decrease of the viscoelasticity at it increases overall interface area, with more area there is more energy dissipating site so the vibrating damping increase. With the decrease of fiber aspect ratio there is the interface area also increases thus more vibration damping. Fiber orientation also play role in vibration damping with different matrix and fiber material there is different orientation of the fiber at which the vibration damping is maximum.

Nor et al. [11] has investigated different factors that affect the sound absorption of coir fiber based composites the factor such as bulk density, fiber diameter, and layer thickness of the coir fiber based composite it has also compared the fresh coir fiber with industrial coir fiber. It has shown that fresh coir fiber has better sound adsorption than industrial fiber, comparison of coir fiber with different diameters has shown that fiber with fewer diameters has better sound absorption. Composite with more bulk density has better sound absorption. Increasing the thickness of the composite has improved the sound adsorption at lower frequency without much change in the value of sound absorption. Koizumi et al. [12] has investigated the bamboo fiber and analyses factors such as fiber diameter, thickness, and density which affect the sound adsorption. The reduced fiber diameter has shown an increase in the sound absorption, the thickness increased has shown an increase in sound adsorption at low level of frequency range. Increased density has also shown increased sound absorption. Porous material gives sound absorption over broadband range of frequency. Senthil Kumar et al. [13] has investigated the vibration damping of randomly oriented banana and sisal fiber in polymer matrix and observed with the increase of the fiber content there is an increase in the natural frequency of the composite of all length thus increase in the stiffness of the material has impact on the natural frequency of the composite. Banana fiber based composite shows with the decrease in the fiber content the damping should increase due to viscoelasticity of the polymer matrix. However, for sisal based fiber composite it shows reverse trend which may due to the interface stiffness and thickness as banana fibers are having smaller diameters which can cause thicker interface and thus increasing the damping of the composite.

Muller et al. [14] has investigated the acoustical property of cotton based composite in thermoset and thermoplastic matrices. Hybrid fleece with phenolic resin binder and fleece with epoxy binder are compared. Phenolic binder has shown better results than the epoxy based binder in higher frequency range of above 2 kHz. The sound adsorption is better with lower degree of compression. The higher compression rate results in lower sound adsorption at every frequency range. Cotton based composite shows good sound adsorption because of high fibrous structure. But fibrous structure has low stiffness thus cannot be used as structural member. Cotton fiber has also been used with other fibers and with different blending ratios. This affects the sound absorption coefficient on different frequency range [15, 16]. Zhang et al. [17] has investigated the sound and vibration damping of PLA fiber with natural fiber. Equal weight of PLA fiber with natural fiber is carded and blended together forming a nonwoven homogeneous mat which is further processed to form a composite panel. The acoustic performance is measured with the help wave number. Cotton-PLA and hemp-knead-PP composites have similar acoustic behavior with coincidence frequency at 2170 Hz and 2134 Hz respectively; as hemp kenaf-PP composite has been used in the automobile industry thus cotton-PLA gives a good alternative. Hu et al. [18] has investigated the damping characteristic of composite from the viewpoint of micromechanical analysis and purposed two damping models, the viscoelastic damping model, and specific damping capacity model. The author also compares the model's result with the experimental data and found considerable agreement between both.

Melo and Radford [19] has investigated fiber reinforced composites with the DMA and has shown trend in which there is an increase in damping loss factor as temperature increases. Senthil Kumar et al. [20] has investigated the effect of layering pattern and chemical treatment on the static and dynamic characteristic of banana and coconut sheath reinforced hybrid composite. The dynamic characteristics are studied with the help of impulse hammer technique layering pattern coconut sheath-banana-coconut sheath layering pattern showing better result the other layering pattern. Sargianis et al. [21] has studied the vibration and sound damping characteristics of natural material based composites and compared with synthetic fiber based composite with the help of wave number. The loss factor is determined by the frequency response function for each composite. Le Guen et al. [22] new has investigated the effect of adding polyglycerol on the flax fiber reinforced composite and has found that at polyol loading under 5 wt% the damping coefficient of the composite was improved by 15–25% when compared to flax fiber composite which is not impregnated by polyol. Talib et al. [23] has investigated the PLA composites with randomly oriented kenaf fiber with different volume fractions of the fiber on DMA at 1 Hz and has concluded that damping peak with more than 50 wt% of fiber has reduced amplitude with respect to neat PLA. Wielage et al. [24] has studied the PP composites reinforced with flax fiber, hemp fiber, and glass fiber with different volume fractions, they concluded that as the fiber content increased the loss factor decreases.

2 Composite and Natural Fibers for Noise and Vibration Absorption

In this section, we have discussed chemical treatment of the fiber which improves the properties of the natural fiber. Treatment of the fiber plays a vital role in many properties of the composite. It cleans the surface of the fiber, reduces the diameter, stops moisture absorption, modifies the surface of the fiber, and improves the adhesion between the fiber and matrix [25–33]. It can also increase the strength of the natural fiber as in case of ramie fiber which went under alkali treatment and register increase in strength of about 4–18% more than the untreated fiber [34]. Alkali treatment also called mercerization reduces the diameter of the fiber. Clean the surface of the fiber and overall produces higher quality fiber [33]. Concentration of NaOH affects the reduction in diameter as shown in Fig. 1. A number of coupling agents such as saline coupling agents can be used to enhance the interfacial bonding between the fiber and matrix and thus improving properties of the composite [35]. Alkalization also improves the fiber-matrix bonding [36].

Theoretical calculations of sound absorption coefficient can be obtained by the predictions of the Delany-Bazley and the Garai-Pompoli models. The acoustic absorption coefficient of fibrous materials is usually determined by porosity, thickness and pore size, etc. The sound absorption coefficient can be measured with the

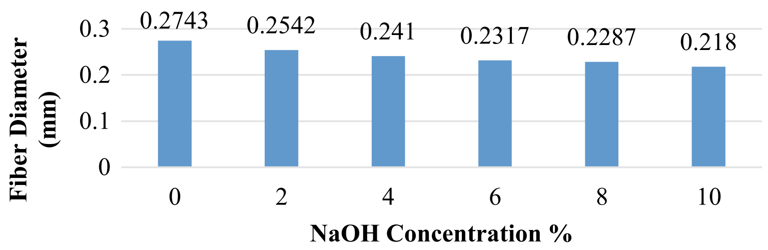

Fig. 1 Effect of NaOH concentration on fiber diameter of the natural fiber [33]

help of an impedance tube tester according to the ASTM standard E 1050 [37]. Schematic diagram of impedance tube MIC1 and MIC2 is shown in Fig. 2.

Three processes constitute the absorption of sound energy in the fibrous material. Initially, when the sound waves hit the fiber the sound wave transmits into the fibers, and due to viscous effect between the fiber frame and air cavities the energy is converted into heat. The heat will be further dissipated due to the temperature gradient between different fibers. The vibration of fiber will also happen due vibration of air in the bulk of the material [38]. Factors such as porosity, bulk density, fiber diameter, grain size, sample size thickness, granular size, and fiber size affect the sound adsorption in the composite material [7, 9]. The sound absorption of any composite material can be increased with more tortuous path. This provides more flow resistivity to the sound wave traveling. This can be achieved by reducing the diameter of the composite, this allows more fibers to be in the unit volume which increases the flow resistivity [39]. Noise reduction coefficient gives value for easy comparison between comparing the acoustic behavior of various materials [36]. Noise reduction coefficient (NRC) can be defined as the arithmetic mean of sound absorption coefficients at 250, 500, 1000, and 2000. NRC values are used as indexes of the sound absorbing efficiency of the material.

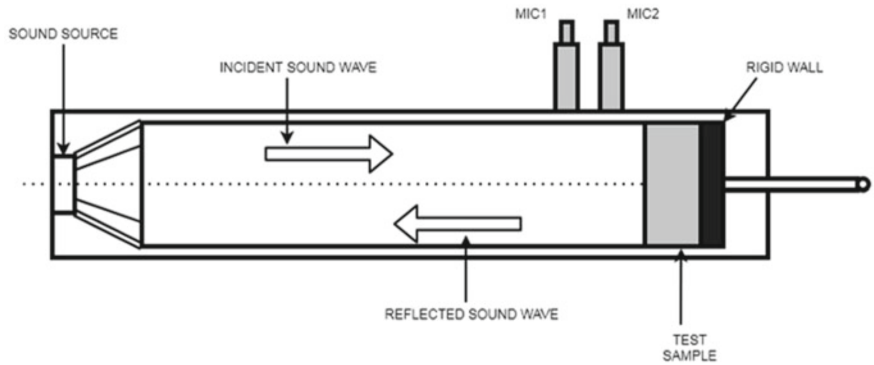

Fig. 2 Schematic diagram of Impedance tube MIC1 and MIC2 denote two microphones [37]

Damping can be categorizing into two groups: material damping and structural damping. Material damping is due to the energy dissipated from the volume of the material and structural damping is due to the relative motion between the different components which causes rubbing [40]. Mechanism of damping in composite differs considerably from the conventional material. Viscoelasticity of the composites plays an important role in the vibration damping of the material. Composites with materials having viscoelasticity can improve the vibration damping of a composite without reducing strength and stiffness of the composite material [41–49]. The viscoelastic layers are very effective in improving the damping (loss factor) of the structure [50, 51]. Vibration damping is caused due to interphase. Interphase is the region between fiber and matrix and is along the fiber length. Interphase properties differ from both matrix and fiber. The properties of interphase play an important role in vibration damping of the composite. Vibration damping is caused due to damage. It is mainly of two types: damping due to energy dissipation and frictional damping. Damping due to energy dissipation is caused due damage to the matrix and fiber which causes crack in matrix and damage the fiber. It causes energy dissipation due to friction at cracks and delamination sites [52, 53]. Frictional damping is caused due to interface slip between unbound regions between fiber and matrix in composite interface. Frictional sliding between the matrix and the nanotubes in the nanocomposite is the main source of dissipation of energy and causes damping [54].

There are numerous ways by which we can measure damping such as logarithmic decrement, the damping ratio, the specific damping capacity, quality factor, loss factor, and specific damping capacity [55]. Loss factor can be easily being calculated from the dynamic mechanical analyzer by which we can estimate the damping of the composite. DMA cannot be used for material with high modulus however it measurements are still important to validate the damping in material [54]. Figure 3 shows the comparison in approximate value of loss factor between the natural and synthetic fiber with natural showing better damping characteristics. Finite element method can also be used to find the damping factor of the composite.

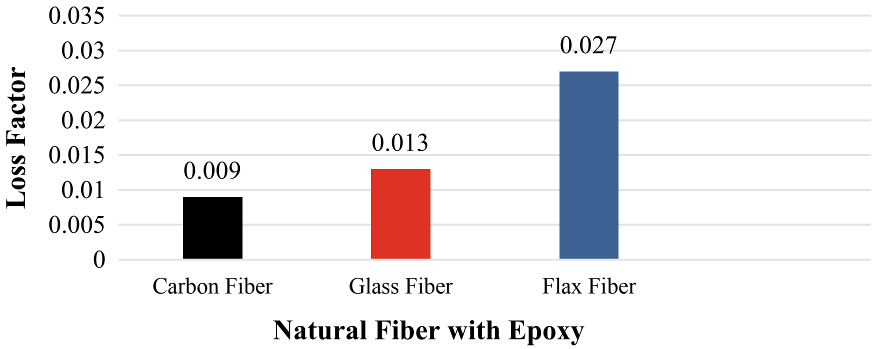

Fig. 3 Comparison of loss factor between the synthetic fiber (GF and CF) reinforced epoxy and natural fiber (FF) reinforced epoxy [56]

3 Conclusions

Natural fibers are already replacing common synthetic fibrous materials for acoustic absorption and vibration damping as in case of automotive industry where natural based composites are becoming more widespread. The use of chemical treatment such as alkali treatment cleans the fiber, reduces the fiber diameter, improves fiber matrix adhesion, and increases the quality of the natural fiber. Porosity of the composite which can be controlled during the fabrication of the composite can increase both vibration damping and acoustic performance of the fiber. More fibrous fiber such as cotton material can also increase the vibration damping and acoustic performance of the fiber however it reduces mechanical strength of the fiber by using hybrid composite of two natural fibers with different bends we can mitigate this issue. Viscoelasticity of the matrix and aspect ratio of the fiber surface influence the vibration damping and acoustic performance of the composite. The properties of the interphase which can change by the chemical treatment also affect the vibration and acoustic performance of the composites. Fiber reinforced PLA composite and bio composite a good alternative to conventional natural fiber based composite as the matrix used is also biodegradable plastic which is even more sustainable.

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