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Vibration Studies on Fiber Reinforced Composites – a Review

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ABSTRACT

Fiber reinforced composites materials have been much more attention in the materials system by the researchers since their unique performance in various structural applications. The addition of fiber and various chemical treatments produces the best mechanical properties of the composite material. However, several authors have described the working mechanism in mechanical composites. Recently researchers have started to investigate the free vibrational behavior of the composites and to find the suitable applications in industry. It is indeed important to represent the vibrational response of the fiber reinforced composites (FRC) toward the anti-vibration applications. Thus, an attempt was made to review the vibration behaviors on natural fiber, synthetic fiber, and filler incorporated natural/synthetic fiber composites. Discussions on the comparison of the natural frequency and damping ratio of various composites bring comprehensive knowledge on vibrational behaviors of various fiber reinforced composites.

KEYWORDS
Vibration; filler; fiber; polymer composites

关键词
振动; 填料; 纤维; 聚合物复合材料

摘要

纤维增强复合材料由于其在各种结构应用中的独特性能，在材料系统中受到了研究者的广泛关注. 纤维的添加和各种化学处理使复合材料具有最佳的机械性能. 然而, 一些作者已经描述了机械复合材料的工作机制. 最近, 研究人员表示要研究复合材料的自由振动行为, 并寻找合适的工业应用. 代表FRC对防振应用的振动响应确实很重要. 因此, 试图回顾天然纤维、合成纤维和掺有填料的天然/合成纤维复合材料的振动行为. 通过对各种复合材料的固有频率和阻尼比的比较, 可以全面了解各种纤维增强复合材料（FRC）的振动特性.

Introduction

The exclusive properties of composites materials can be used in the superior for several applications. The use of the fiber reinforced composites (FRC) is increasing in several applications because of its higher specific strength, higher specific modulus, easy tailorability, and good formality. FRCs are the most influential and alternative ones to commercial materials such as metal and ceramic materials (Adekomaya et al. 2016; Messiry and Mohamed 2018). They have been used in many engineering fields such as construction materials, the structure of aeronautical, sports materials, and wind turbines (Sudha and Thilagavathi 2018; Zaman, Gutub, and Wafa 2013). The increasing production of high-performance products from FRCs is noted in

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current scenarios. However, the development of the importance of the FRCs can be observed by many researchers (ElAgamy and Laliberté 2016; Kalusuraman et al. 2016; Mokhothu and Jacob John 2015; Pal and Kumar 2016; Tan et al. 2015).

At present, many studies are attentive to the mechanical characteristics such as tensile, impact, and flexural of the many fiber reinforced composites. The FRC offers the best usage in the engineering field which gets affected by the consequence of dynamic loading. The undesirable effects, noise, and wear due to the vibrations will decrease the life of the materials (Messiry and Mohamed 2018; Muralidhar 2015). Hence the most important thing is to control the vibration of the materials. The damping is must more increase in the hot topic in the researcher mind because of its effect. The damping and vibration of behaviors of the composite can be adjusted by a fiber-matrix interface, chemical treatment, and the fiber loading variance. As far as the best of concern, several publications discussed about the vibration and damping behavior (Chandra, Singh, and Gupta 1999; Finegan and Gibson 1999). The aim of this review paper is to gather all the knowledge of the vibration and damping of FRCs and the report is summarized in the case of natural fiber reinforced polymer composites, synthetic fiber, and filler-filled composites. This could be useful for researchers to the development of vibration and damping behaviors of the composites.

Vibration on natural fiber reinforced polymer composites

The research work carried on (Kumar et al. 2014) fiber volume loading and layering pattern effects on sisal and cotton fiber/polyester composites on mechanical and vibration features. It was found that the higher values of mechanical properties were obtained at 40% fiber loading. The higher natural frequencies are obtained at 30% sisal fiber content which ranges from 34 to 300 Hz also stated that the fiber content will enhance the natural frequency of materials. Bennet et al. (2015) investigated on the vibrational behavior on the Sansevieria cylindrica/coconut sheath (CSC) hybrid composites and found that the coconut sheath/sansevieria/coconut sheet hybrid composite offered the high natural frequency at all three modes. The chemical treatment also influenced on the damping behaviors and the natural frequency is increased from 28.53 to 48.25 Hz after the treatment for CSC compotes and similar trend was noted in the damping ratio (0.0502 to 0.0612). Another research explored (Senthil Kumar et al. 2014) on the free vibration behavior of short sisal fiber and banana fiber polyester composite. They reported that the damping values increases as the fiber loading increases. The 3 mm fiber length with 50% fiber content achieves improved mechanical properties for SFPC. The 50 wt.% fiber loading yielded the best result in mechanical properties for 4 mm fiber length of BFPC. Kalusuraman, Siva, and Aslan (2020) conducted the work on luffa fiber about the vibrational properties and stated that the chemical treatment enhanced the mechanical and damping behaviors of the composites. The luffa composites (40% fiber loading) showed an increase in natural frequency from 67 Hz to 110 Hz after NaOH chemical treatment.

Figure 1 shows the natural frequency of the various composites based on mode-I (bending). It is based on the highest values obtained in the mode for the different composites. It was observed that CBC (coconut/banana/coconut sheath) polyester composites hold higher natural frequency in the mode-I. The lower natural frequency of 12.66 Hz was noted for 10% hemp polypropylene composites. The different layering pattern increases the natural frequency when compared with single layer/fiber.

Figure 2 shows the damping values for various composites prepared by different fibers and matrix. It is plotted by considering the highest values noted in the various research paper while in mode-I (bending). Even though the damping ratio values are available for various treated fiber, the values are taken for untreated fiber for better interpreting of data. It was noted that CCC (Coconut sheath/Coconut sheath/Coconut sheath) polyester composites hold the higher damping value of 0.80234. The CCC composite is applicable to absorb more vibrations that are applied in industrial applications.

Munde, Ingle, and Siva (2018) explored vibration and damping properties of coir fiber reinforced polypropylene composites. In this work, the fabrication of composites was made by varying the wt.% (0–30% fiber content) and rise in fiber content which led to a decrease in the damping properties. The

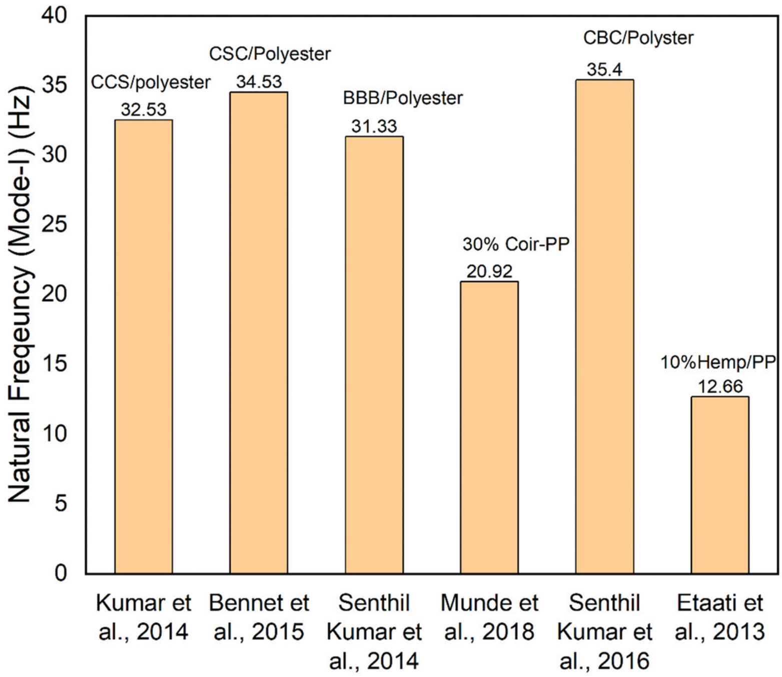

Figure 1. Comparison of natural frequency of the various natural fiber composites under mode-I.

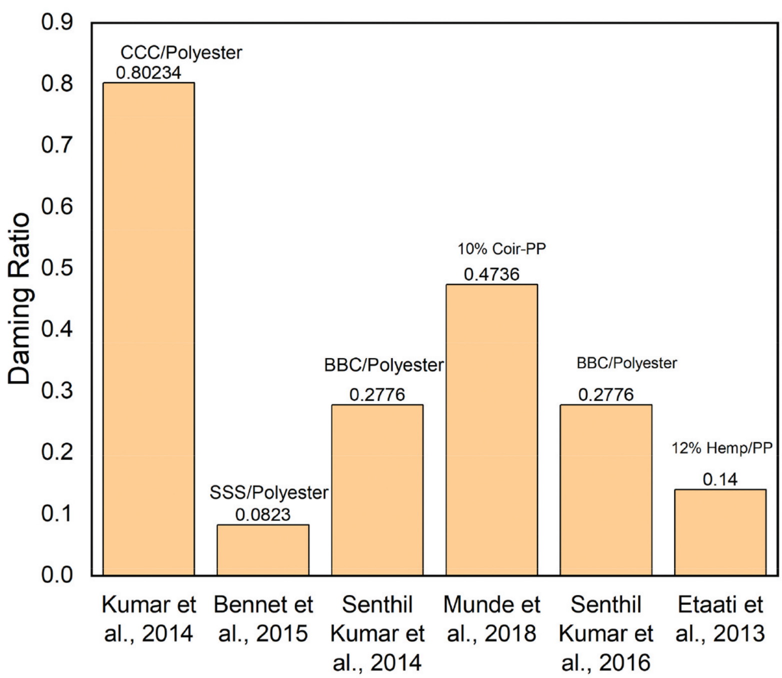

Figure 2. Comparison of damping ratio of the various natural fiber composites under mode-I.

natural frequencies were noted for 30 wt.% composite was higher than other modes. Rajesh and Pitchaimani (2016) performed the study on free vibration and the buckling properties of jute woven/polyester composites. In this work, dissimilar weaving types such as plain, Herringbone, and Basket are used. The natural frequency at the pre-buckled section was decreased when compared to the post-buckled section. A reverse trend is observed for the damping behavior. Senthil Kumar et al. (2016) explored the stacking order effects on the vibration behavior of woven coconut sheath and short banana/polyester hybrid composite for untreated and treated (alkali) conditions. The CBC layered pattern and treated fiber holds higher damping.

The vibration studies on noil hemp fiber-polypropylene composites was investigated by Etaati et al. (2013) for different loading with a range of 0 to 60 wt.% with an increment of 10% was done. It also explored the effect of coupling agent on vibration behavior. The reported is the highest damping ration found for the 30 wt.% of noil hemp composites. The improvement in storage modulus was noted for 30 wt.% noil hemp reinforced composites with the addition of POE-MAH and PP-MAH. Jena (2018) carried out vibration studies on short bamboo/polyester composites with different fiber content (10 wt.% and 15 wt.%). It is observed that the stiffness of the composite has been increased as a result of increasing the fiber content, so the natural frequency of the higher fiber content composite was increased. Rana, Gupta, and Srivastava (2017) performed the dynamic mechanical properties of the short sisal/epoxy composites. The hand lay-up method was used to fabricate the composites with different fiber size lengths (5, 10, 15, and 20 mm) with 30% fiber content. It is observed storage modulus and loss modulus were noted as high for the composites with 15 mm fiber length. The vibration properties of flax fiber reinforced composite were explored (Prabhakaran et al. 2014) and noted that the damping of flax fiber composite was 51% higher than that of the glass fiber composites. Further, the natural fiber composite is produced a better result in damping properties. The damping using the free vibration technique for wood-filled polypropylene (PP) composites was done by Yang et al. (2010). The increase in fiber loading measured a decrease in damping in wood flour-filled PP composites. But no significant effect on compatibilizer has been noted. Another investigation (Rahman, Jayaraman, and Mace Rahman, Jayaraman, and Richard Mace 2018) explores damping on flax fiber reinforced PP composites using the vibration measurement. The composite was fabricated using vacuum bag molding with various fiber loading (31%, 40%, and 50%) and orientations (45°, 60° and 90°). It is observed that the fiber orientation is a most important parameter for influencing the damping than the fiber loading. Investigation on the vibration damping on sisal fiber reinforced polypropylene composites was done by Munde, Ingle, and Siva (2019). The composites were fabricated with different fiber loading (10%, 20%, and 30%). The impulse hammer technique was used to find the damping behavior of the composites. The 30% fiber loading shows the best natural frequency and low damping.

Vibration on synthetic fiber reinforced composites

Biswas and Ray (2017) investigated the vibration studies on the carbon/glass hybrid composite to find the stacking sequence effects. The addition of carbon at both extremities gave a good result in increased vibration properties. In addition to that, the finite element model (FEM) has been developed on TSDT (third-order shear deformation theory), which assists to find predicted natural frequency which is closer to the experimental values than the FSDT (first order shear deformation theory). Another research reported (Assarar et al. 2015) the damping behaviors of flax carbon hybrid composites with an effect of stacking sequence. A significant increment in damping was found for flax-carbo hybrid laminates than the flax layers were outside the carbon laminates. They reported that some flax fiber carbon hybridization improved the damping properties of composites.

The mechanical behaviors and vibration properties on (Murugan, Ramesh, and Padmanabhan 2016) thin-walled glass(G)/carbon hybrid composites reported that the CGGC is superior to GCCG in vibration characteristics. Basalt (B) and glass (G) fiber (unidirectional & plain weave condition)/epoxy composites were developed by Alexander and Augustine (2015) using the compression molding, and they investigated the vibration characteristics on it with varying boundary conditions. A higher natural frequency was obtained for G-epoxy composites over the B-epoxy composites. The woven fabrics produced a high natural frequency when compared to unidirectional. Natural frequencies are noted as higher in value for fixed-fixed end conditions as soon as compared to simply supported and cantilever cases. Naghipour, Taheri, and Zou (2005) explored the vibration characteristics of five kinds of three-layered glued laminated beams with three layers of glass polymer sheets (GRP). They used the logarithmic decrement method to find the damping ratio through a response of frequency. They reported that the average value of damping of reinforced beam was 12% higher than that of GRP reinforced beam.

Another research explored (Amuthakkannan and Manikandan 2018) the vibration and dynamic mechanical properties of basalt/polyester composites. Untreated, acid treated, base treated fiber was used for making the composites. The natural frequency of untreated fiber composites showed better than the treated fiber composites. From the DMA, the untreated fiber composites were reported for getting increased in the storage modulus, damping factor, and loss modulus. The work has been (Bozkurt and Enver Gökdemir 2018) conducted on the basalt fiber addition effects on vibration properties of carbon/epoxy composites (CFRP). The composite was prepared by vacuum bag molding. The gain in basalt fiber content displays improvement in damping and drop in natural frequency of the composites (CFRP). They explored that the increasing basalt content in the range 0 to 34.25% which in turn led to enhancing the damping coefficient up to 61%. It also observed that the vibration properties could be varied by the hybrid of the basal fiber with CFRP. Adali and Verijenko (2001) investigated the optimum stacking sequence on the graphite/glass hybrid composite under free vibration. The stacking sequence effects have been analyzed by graphite fibers in outer layers and glass fibers in internal layers through discrete ply angles. The influence of aspect ratio on the optimum stacking arrangement was investigated. Erkliı, Bulut, and Yeter (2015) conducted the vibration studies on hybridizing of carbon, kevlar, and sisal-glass fibers. The experiments were conducted in three boundary conditions like free, clamped, and simply supported, and it has been explored that hybridizing composite influenced the frequency and damping of material in the significant manner. Botelho et al. (2005) explored the damping behaviors of carbon epoxy composites. They used glass/epoxy, carbon/epoxy, and combination with aluminum sheets for finding the dynamic properties of composites. It has been observed that the damping value of glass epoxy alumina composites has become 44% greater than the carbon-epoxy composites. Vibration studies on aluminum epoxy/glass epoxy hybrid composites were explored by Chen, Ren Chen, and Der Chien (2009) by considering layer number, thickness ratio, and type of material. They reported that decreasing natural frequency was observed with increasing the stacked layer and layer thickness. A research was carried out by Premkumar, Siva, and Amico (2020) on the hybrid effects on the static and vibrational behaviors of the Brazilian curauá/basalt hybrid composite. It was reported that vibrational properties are also enhanced upon the incorporation of curauá fibers into the basalt fiber composites.

Figure 3 shows the natural frequency of the various synthetic fiber reinforced composites. The graph is drawn based on the result obtained in the free vibration testing under the cantilever support condition for mode-I. As per the data, CFRP holds the natural frequency value of 100.7 Hz. The next higher value is noted in the curauá fiber polyester composites. The basalt polyester composite has been noted as having low natural frequency among all mentioned composites in the above diagram.

Figure 4 shows a comparison of the damping ratio of various synthetic fiber composites. The curauá fiber polyester composites show the higher damping ratio mentioned in the graph. Hence curauá fiber composites can be used for anti-vibrational applications. The basalt polyester composites have been noted as having a higher damping ratio next to curauá fiber composites.

The basalt fiber epoxy composites record the low value of the damping when compared to all the mentioned composites.

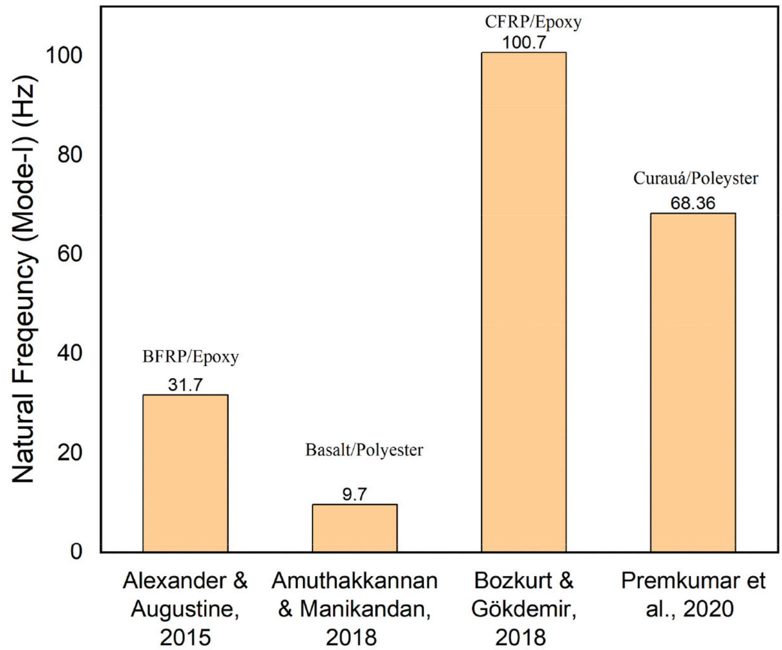

Figure 3. Comparison of natural frequency of different synthetic fiber composites.

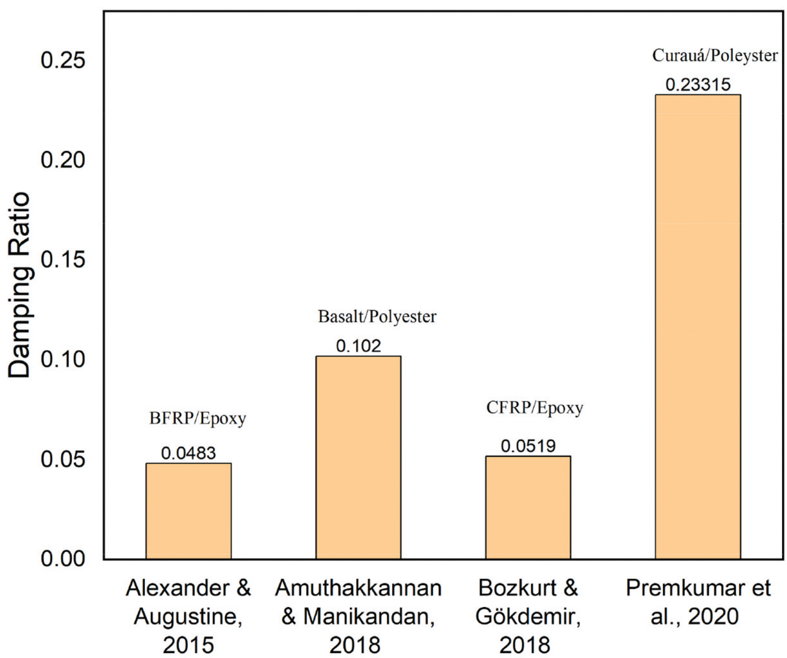

Figure 4. Comparison of damping ratio of different synthetic fiber composites.

Table 1. Values of natural fiber and damping ratio of filler incorporated composites.

Description	Natural Frequency in Hz (Mode- I)	Damping ratio	Reference
Banana fiber for 10% redmud	70.76	0.05174	Arumuga Prabu et al. (2014)
30% Jute nano clay	55.31	0.1958	Arulmurugan and Venkateshwaran (2016)
3% nano clay/coconut sheath	23.19	0.07813	Rajini et al. (2013)
20% borax filler/sisal-glass	108.548	0.355–5	Erklig and Bulut (2016)

Vibration on filler incorporated fiber reinforced composites

Arumuga Prabu et al. (2014) investigated the mechanical and vibration properties of red mud effects on banana polyester hybrid composites. The red mud particle size (4, 6, and 13 μm) and the fiber wt.% (2, 4, 6, 8, and 10%) were varied. The higher mechanical properties were found at 8% fiber content; the highest natural frequency and damping properties were found at 8 wt.%. fiber content and 6 μm red mud particle size. Arulmurugan and Venkateshwaran (2016) performed the examination on the vibration analysis of jute fiber/polyester composites. The inclusion of nano-clay improves the mechanical properties. The composites by varying fiber content (5, 10, 15, 20, 25, and 30 wt.%) and varying filler content (1, 3, 5, and 7 wt.%) were fabricated. They affirmed that the 5% addition of the nano-clay and 15 wt.% fiber content yielded improved mechanical properties and vibration behavior. Another research (Erklig and Bulut 2016) explored vibration and damping response for the sisal-glass/epoxy Composite with the addition of borax filler. The composites were prepared with various particle loadings (5, 10, 15, and 20 mass %). The vibration test was performed by the modal analysis, the result showed that the 5% mass particle loading, explored that increased in vibration and damping properties, later on, it decreases in trend was noted.

Higher values in damping and natural frequency are tabulated in Table 1 as per various research papers related to filler incorporated natural/synthetic fiber reinforced composites. Addition of redmud in the banana fiber shows higher values when compared to nano clay in the natural fiber composites. But it seems in reverse order in the case of damping ratio.

Rajini et al. (2013) reported the effect on MMT (montmorillonite) clay in the coconut sheath polyester composite. In this work, the enhanced vibration properties were obtained up to 3% clay inclusion in the coconut sheath polyester composites. The vibration studies were carried on nano clay-filled jute fiber epoxy composites by Ramakrishnan et al. (2021). It was noticed that the natural frequency was improved after the treatment and nano-clay addition. Especially, 5% of NaOH treatment and 5 wt.% of nano-clay addition showed better results.

Conclusion

In this review, a comparative result from various authors on natural frequency and damping ratio is addressed. Following are the specific observations observed from the literatures.

- The natural frequency and damping behaviors concerning the effects of fiber loading, the effect of filler, the surface treatments, and energy dissipation have been reviewed.
- It was detected that the orientation of fiber, fiber stacking order plays an important role in obtaining the natural frequency and damping. The interface region is one of the important regions in vibrational behaviors.
- Recent works are going on the interfacial design to enhance the damping behaviors of the composite. The addition of filler in the fiber reinforced composites enhances the damping properties.
- Thus, the interface damping is the good platform in the vibration control of fiber reinforced composites.

- Few researchers have worked on the filler incorporated in the natural/synthetic fiber reinforced composites to study the vibrational behaviors. There is some scope on filler vibration studies on various filler incorporated FRC.
- Numerical modeling has a great scope for future work. But the preparation of the fiber property could be challengeable one for the researchers.

Highlights

- Review of the vibration behavior of natural, synthetic and filler incorporated natural/synthetic fiber composites.
- Orientation and stacking order of natural fiber plays a vital role in obtaining the natural frequency and damping.
- The interfacial adhesion between synthetic fiber and matrix improves the mechanical property.
- Addition of filler in the natural/synthetic fiber composite enhances the vibrational behavior.
- Scope for numerical modeling to predict the damping and natural frequency of the composites.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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