Journal of Fibers and Polymer Composites 2 (2): 130-144 (2023)

Journal of Fibers and Polymer Composites

https://journals.gesociety.org/index.php/jfpc/index

EXPERIMENTAL AND NUMERICAL INVESTIGATION OF FIBER DIRECTION ON THE VIBRATION PROPERTIES OF ANANAS COMOSUS LEAF REINFORCED EPOXY COMPOSITE BEAMS

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Abstract. *Technological evolution and environmental awareness have driven the improvement of quality and renewable products, especially in natural fiber-reinforced composites. This study aims to analyze the stiffness and personal frequency of ACL fiber-reinforced composite beams due to the influence of the fiber direction. Next, compare experimental values with numerical. Composite beams are produced by varying the direction of the fibers 0°/0°/0°, -45°/0°/45° and -90°/0°/90° then supported by a simple support (clamp-roll). The exciter position is placed at 0-50 cm along the composite beam, then determine the value of stiffness and vibration behavior experimentally and numerically. This research indicates an increase in the stiffness and personal frequency of composite beams in the fiber direction 0°/0°/0°. The experimental values are also greater when compared to the values obtained numerically. These findings make it possible to use ACL fiber to manufacture composite beams with vibration-enabled characteristics for various applications in engineering materials subject to vibrational forces.*

Keywords: *Ananas comosus leaf fiber; laminated composite beams; fiber direction; stiffness; natural frequency*

1. Introduction

In recent years, the use of composites as metal substitute materials has been increasingly developed [1]. This is because composites have several advantages, including high stiffness and strength [2], vibration-damping properties [3], excellent corrosion resistance [4], being lightweight [5], low production costs [6], and containing non-hazardous materials [7]. These advantages make composites widely applied to construction, maritime, military, aerospace, automotive, and various other applications [8]–[12].

The most used composites in the industry are carbon fiber composites and glass fiber composites. Fiberglass composites are widely used in boats, car interiors, and water tanks. While the use of carbon fiber composites is used in the aerospace, automotive, and weaponry industries because they have stiffness, high tensile strength, and a much lighter weight compared to steel, the weight is only about a quarter compared to steel [13]. In addition to using glass and carbon fiber composites, natural fiber composites have also been developed as an alternative to synthetic

Received February 26, 2023; Accepted October 22, 2023; Published October 30, 2023

https://doi.org/10.55043/jfpc.v2i2.74

fiber composites [14], [15]. Composites with natural fiber reinforcement have advantages that synthetic fiber composites do not have, such as being sustainable and renewable because the fiber raw materials are widely available in nature, biodegradable and environmentally friendly because the material is organic and can be naturally recycled by the environment [16], [17].

One of the natural fibers that have the potential to be used in the utilization of composites is a natural fiber derived from Ananas Comosus Leaf (ACL) [18]. Pineapple leaves are raw materials for ACL fiber, which are usually allowed to accumulate in plantation areas and become waste that can potentially damage the environment. This provides an opportunity for ACL fiber to be used as a reinforcing fiber in the manufacture of composites so that it can be a solution to reduce plantation waste. Many studies have studied and discussed natural fibers from ACL Fiber both mechanical properties [19], physicochemical properties [20], properties [21] and thermal properties [22]. However, as far as the author's observation, no one has discussed vibration behavior in (ACF), especially in layered lamina composite applications with variations in the fiber direction, so there is still a chance to be used as an engineering material in applications subject to vibrational forces.

Using natural fibers, including ACL fibers as fillers in composites, is a significant strategy to improve environmental sustainability that has been proven to minimize environmental problems and public unrest [23]. Natural fiber fillers can reduce the amount of polymer resin required in composites, resulting in significant energy savings and reduced greenhouse gas emissions with implications for reducing environmental impacts much lower than traditional glass fiber composites throughout their life cycle [24]. Natural fiber fillers can also improve mechanical and dynamic properties.

Natural fiber composites (NFCs) are also increasing in various applications, including the automotive, railway, and building industries [25]. For example, NFCs produce lightweight automobile parts like door panels and dashboards. NFC is also used to produce sustainable building materials, such as roof shingles and insulation panels, including some engineering applications that receive forces in the form of vibrations because of their excellent characteristics in working in environments subject to vibration [26].

Vibration analysis of materials is a fundamental process in mechanical engineering [27]. Using natural fiber composites in the structure and construction of machines must meet the required standard of mechanical properties and vibration characteristics to support the material's ability and prevent failure due to working vibration. Under vibration conditions, materials operating at natural frequencies will resonate and result in fatal system failure [28]. When the frequency of the excitation force coincides with one of the system's natural frequencies, a resonance condition occurs and produces a significant deviation [29] that can cause damage to the system. So, it is essential to determine the vibration properties, mainly the natural frequency and stiffness of a material, including ACL fiber-reinforced lamina composites. Recently, natural fibers have been highly recommended for some application areas where vibration is a significant concern. Natural fiber composites have a higher vibration-absorbing capacity than conventional materials due to their high specific strength, viscoelastic behavior and high damping properties [30], [31].

This investigation details the impact of ACL fiber reinforcement directions on the stiffness and vibration behavior (natural frequency) of ACL fiber-reinforced composite beams. Experimental test results and calculations using the finite element method are used to determine the correlation between the two techniques applied. We hope that the results of this research can contribute to the behavior of the ACL fiber directions to the vibration behavior that occurs in composite beams for the applied boundary conditions.

2. Methods

2.1. Materials

In this work, the ACL fiber was derived from pineapple plant leaves. The leaves (AC) were collected from a plantation in the Harau District, Enrekang Regency, South Sulawesi Province. The chemical used is NaOH Merck, Germany. While PT. Justus Kimia Raya supplies the epoxy resin. Information regarding the material used is presented in Table 1.

Table 1. The preparation of materials

Parameters	**Information**
Ananas Comosus Leaf	± 18 Month
Fiber fraction	40%
Treatment	With 5 wt % NaOH concentration for 2 hours at room temperature
Fiber arrangements	Continuous
Fiber direction	0/0/0, -45/0/45, -90/0/90
Ratio of epoxy resin to hardener	2:1

2.2. Preparation of ACL Fiber

Pineapple leaves, the raw material for ACL fiber, are separated manually from the parent tree by cutting at the base (Figure 1). The fiber then undergoes a retting procedure by placing the leaves in water and soaking them for 21 days to help separate the fiber bundles and unwanted substances. Then scraping is carried out using a knife that is not too sharp to remove any substances still attached or remaining on the fiber, as shown in Figure 2. The leaves that have become fiber are cleaned, combed and rinsed, then dried for three days to remove excess water from the fibers.

Figure 1. Raw materials for ACL fiber

Figure 2. Scraped ACL fibers

2.3. Treatment of ACL Fiber

The required amount of fiber is soaked in a dilute alkaline solution and ACL fiber is treated with alkali in 5 wt % NaOH for 2 hours [32], [33]. This selection can improve physical, chemical and mechanical properties better [34], an increase in wt % NaOH can damage the fiber [33]. Fibers that have received alkaline treatment are washed with distilled water until clean fibers are obtained. Finally, the fibers are allowed to dry in the open air for three days and then ready to be used as reinforcement in the composite.

2.4. Fabrication of composites

Composite manufacture begins with arranging the fibers according to a predetermined orientation. For convenience, the fibers are arranged and attached to a pattern adjusted to the mold (Figure 3a). The epoxy resin and hardener are mixed at a ratio of 70:30 according to the manufacturer's requirements. This mixture is then stirred to achieve homogeneity and left for a while to remove air bubbles. The resin mixture is then used to make composites. Then each fiber layer is wetted individually by a hand-layup technique using a brush, ensuring that the matrix is uniformly distributed in each layer. The layers were carefully layered in the appropriate stacking order. Layers were made in the order 0/0/0, -45/0/45, -90/0/90 for the first, second and third specimens, respectively. After all fiber layers are wetted with resin, pressure is applied to the pile to solidify the composite material and prevent swelling of the composite. Furthermore, the curing process was carried out overnight at room temperature and then post-cured in the oven at 50C for 5 hours. Specimens ready for tensile and vibration tests are shown in Figure 3b.

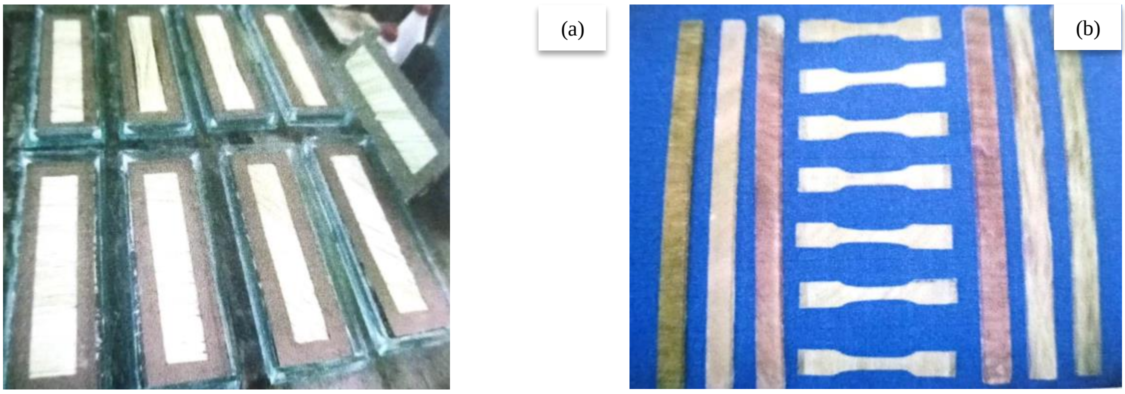


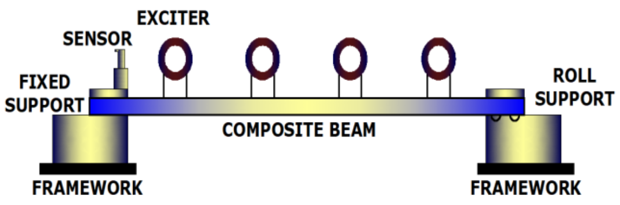
Figure 3. (a) Composite mould (b) tensile and vibration test specimens

2.5. Tensile test

Tensile testing was carried out on the test specimens using the Universal Testing Machine HT 2402 with a maximum load of 20 kN at room temperature 25°C and a displacement rate of 1 mm/min. Tensile testing is carried out until the test specimen breaks, during which force or stress testing and rod length or strain changes are monitored and presented in the form of a stress-strain curve. Experimental test validation for each composite configuration was confirmed by testing three specimens. The composite specimen used for tensile testing complies with the ASTM D638-02 standard [35].

2.6. Vibration test

The vibration test was carried out using a Vibration test tool model VT 8204 Vibration Analyzer. The vibration testing instrument is shown in Figure 4. The composite beam is supported on a hinge-roll basis and the vibration motor (exciter) is varied at 10 cm, 20 cm, 30 cm, 40 cm and 50 cm. The composite in this vibration test uses ASTM E756-05 [36]. The sensor is placed at the end of the pedestal and retrieves vibration data from the vibration sensor. The results obtained are in the form of a vibration spectrum with a graphical display of natural frequency (ωn) displayed on the monitor screen so that natural frequency and stiffness can be identified.



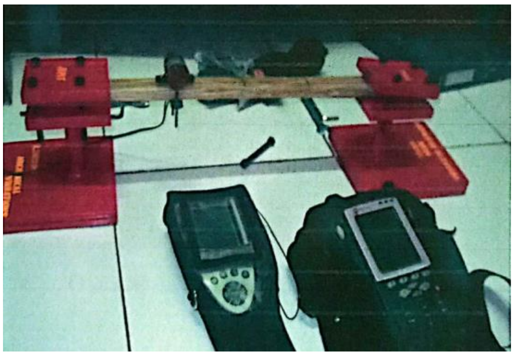


Figure 4. Vibration testing instrument

2.7. Vibration test

The numerical analysis uses the finite element method by dividing the beam into five elements, with the length of each element being the same, as shown in Figure 5. Calculations to obtain the individual frequency (ωn) and stiffness (S) are carried out using the help of Matlab software with the following equation 1: [37], [38].

$$\omega n = \sqrt{\frac{[k]}{[m]}} \quad (1)$$

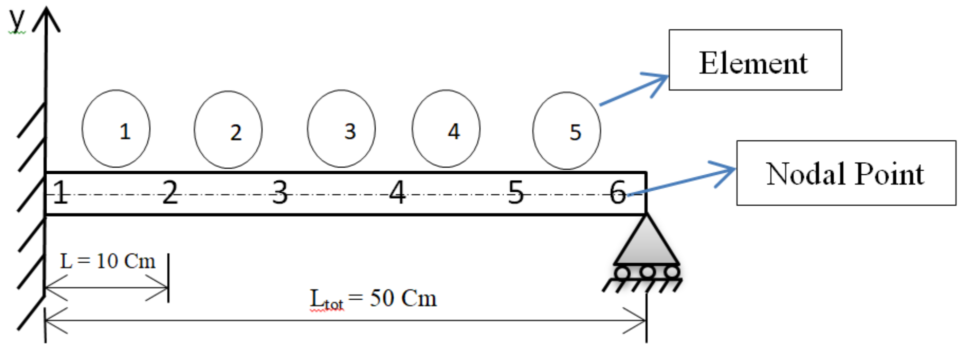


Figure 5. Division of Composite Beam Elements

3. Results and Discussion

3.1. Young's modulus

A tensile test was carried out to determine the value of Young's modulus. The value of Young's modulus is used as one of the parameters in numerical calculations using the finite element method. Figure 6 shows the young's modulus value of the ACL fiber composite with fiber directions 0˚/0˚/0˚, -45˚/0˚/45˚, -90˚/0˚/90˚ of 515.875 N/mm^2, 416.687 N/mm^2, 386.875 N/mm^2, respectively. The graph concludes that the 0/0/0 fiber direction gives Young's modulus higher than the -45/0/45 and -90/0/90 fiber directions. Composites with fiber direction 0/0/0 distribute the force entirely in the longitudinal direction, thus having the highest Young's modulus value, as reported by Wang [39].

While the decrease in Young's modulus in the fiber directions -45°/0°/45° and -90°/0°/90° is caused by only one lamina, namely the 0° direction, which distributes the force completely. The lowest modulus of elasticity of the ACL fiber composite is in the fiber direction -90°/0°/90° due to 2/3 of the lamina in the 90° direction so that most of the fibers distribute the force in the transverse direction; this significantly affects the mechanical properties of the composite, including a decrease in the value of Young's modulus [40], [41].

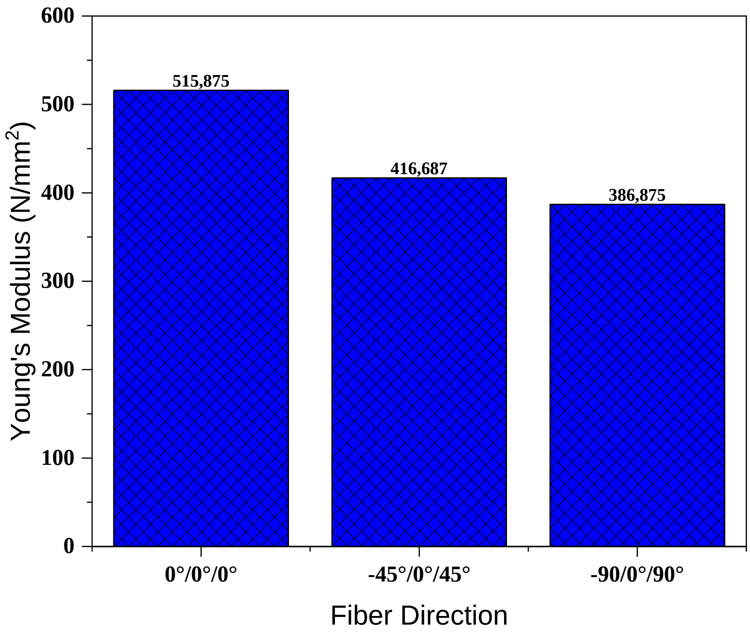


Figure 6. Young's modulus VS Fiber Direction of ACL fibers composite

3.2. Effect of fiber orientation on the stiffness

Figure 7 shows the stiffness-position exciter graph of the composite vibration test results. The highest composite stiffness with fiber direction reinforcement 0°/0°/0° at the 10 cm exciter motor position was 877600.98 N/mm^2 experimentally and 8377254.56 rad/sec numerical (FEM). Followed by the stiffness of the composite with fiber direction -45°/0°/45° at the exciter motor position of 10 cm of 819216.16 N/mm^2 experimentally and 7908543 rad/sec numeric (FEM). Then the stiffness of the composite in the fiber direction -90°/0°/90° is 786917.98 N/mm^2 experimentally and 7600881.02 rad/sec numerical (FEM). At the same time, the lowest stiffness is in the 50 cm exciter motor position, which is right at the support for all variations in the fiber direction.

This graph shows the highest stiffness values of composite beams in fiber directions 0°/0°/0°, -45°/0°/45° and -90°/0°/90° respectively, for all variations in the position of the vibratory motor alignment and alignment of the fibers in the lamina along the composite beam in the longitudinal direction so that it can distribute the force it receives thoroughly along the longitudinal direction so that it can optimally withstand the applied load. This can improve the mechanical properties so that it is oriented towards increasing the stiffness value of the composite beam [42]–[44]

The stiffness value of the composite beam continues to decrease as the fiber direction increases. This can be attributed to delamination and the increase in fiber direction angle, which is getting closer to the critical orientation angle [45]

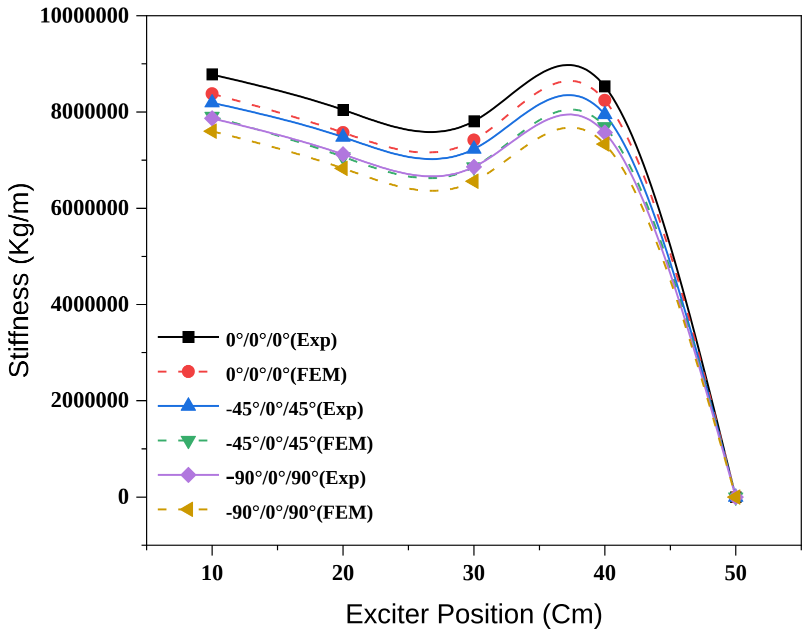


Figure 7. Graph of composite beam stiffness with various exciter positions

3.3. Effect of fiber orientation on the natural frequency

Figure 8 presents a graph of the natural frequency-exciter position of composite beams experimentally and numerically. The graph shows the change in the natural frequency value as the position of the exciter motor changes. The highest natural frequency value was at the vibratory motor (exciter) position 10 cm from the pedestal for the 0°/0°/0° fiber direction, namely 4870.21 rad/sec experimentally and 4758.28 rad/sec numerical (FEM). In contrast, the value of the lowest natural frequency, both experimentally and numerically, is 0 rad/sec at the end of the beam, namely at the exciter position of 50 cm for all variations in fiber directions.

It can be seen that there is a decrease in the natural frequency values in the -45°/0°/45° and -90°/0°/90° fiber directions. The natural frequency values decrease as the fiber orientation angle increases [46]–[48]. This can be caused by the reduced fiber reinforcement in the composite beam in the longitudinal direction so that there will be a reduction in the length of the individual fibers in the longitudinal direction of the beam so that the ACL fiber reinforcement decreases significantly. This also impacts reduce the stiffness of the composite, so it has implications for a decrease in natural frequency [49]. As reported in previous findings, the value of the natural frequency of a composite beam is always directly proportional to its stiffness value [44], [50], [51]

The results on the graph also show a trend of increasing natural frequency values at the position of the exciter motor at 40 cm. This is different for the cantilever support type because that position is close to the roll pedestal, so it can increase the natural frequency value. Meanwhile, the natural frequency value at the 50 cm position always has a value of 0 because, at that position, it is the support position.

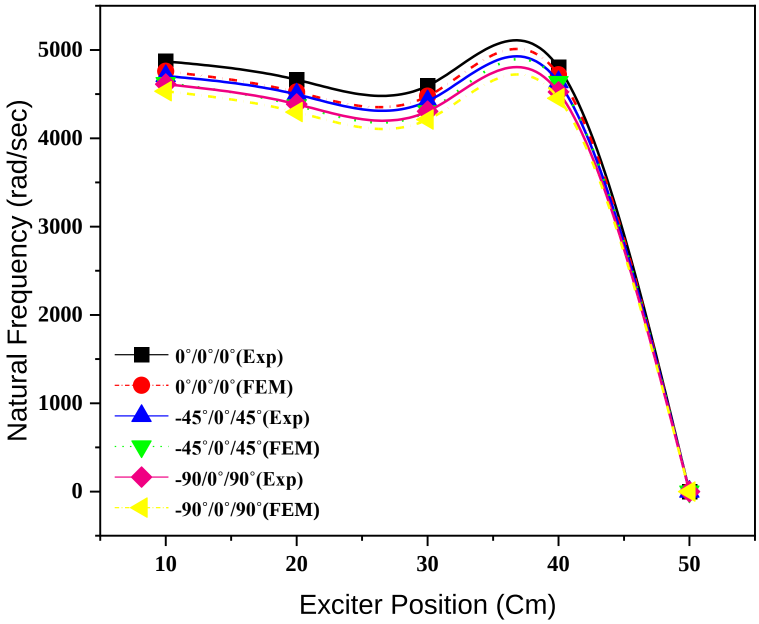


Figure 8. Graph of natural frequency composite beams with various exciter positions

3.4. Comparison of experimental and numerical results on composite beams

Data are shown in Table 2 provides information about errors in natural frequency and stiffness experimentally and numerically (FEM) ACL fiber composite beams with each fiber direction variation. It is essential to confirm the findings obtained from experimental studies with numerical findings to ensure the alignment of the results obtained, including avoiding measurement or calculation errors [50], [52]–[54].

Table 2 shows the most significant error value is 3.95% in the fiber direction 0°/0°/0° with an exciter position of 20 cm. In comparison, the slightest error value is 0% each in an exciter position of 50 cm for all fiber directions. However, the results obtained between experimental and numerical are not much different. These results are still lower when compared to the results obtained in other jobs, which reach an error value of 4.91% [53]. In the end, the results of numerical values can be used to confirm the experimental values obtained in this work. The values obtained experimentally tend to be greater than the numerical values. This can be caused by the accuracy of data collection of the equipment used and the instrument's sensitivity when data collection occurs, especially when installing the test material on clamp and roll supports.

Table 2. The preparation of materials

No	Fiber direction (°)	Exciter position (cm)	ωn error (%)	S error (%)
1	0°/0°/0°	0	0	0
		10	2.32	2.59
		20	3.05	3.97
		30	2.58	3.08
		40	1.37	1.42
		50	0	0
2	-45°/0°/45°	0	0	0
		10	1.74	1.49
		20	2.83	3.57
		30	2.65	3.25
		40	1.61	1.23
		50	0	0
3	-90/0°/90°	0	0	0
		10	1.71	1.43
		20	2.07	2.12
		30	2.2	2.36
		40	1.58	1.17
		50	0	0

4. Conclusions

This study investigates the effects of modifications in fiber orientation on the Young's modulus, stiffness, and natural frequency of ACL fiber-reinforced laminated composite beams. The beams are supported by clamp-roll supports. The fiber direction significantly affects the values of Young's modulus, stiffness, and natural frequency in composite beams. Specifically, the highest values are seen in the 0°/0°/0° fiber direction, while the lowest values are found in the -90°/0°/90° fiber direction. The experimentally acquired natural frequency and stiffness values exhibit higher magnitudes compared to the numerically computed values. The primary contribution of this study is in the importance of comprehending the orientation of fibers inside the composite reinforcement and the boundary conditions employed in the system in order to attain optimal values for the natural frequencies of the system. Additional research will be conducted to examine the impact of differences in boundary conditions on the stiffness and vibration characteristics of composite beams with variations in the direction of the fibers.

Based on the findings of this study, there is an increase in stiffness and personal frequency with a specific fiber direction. This shows favorable characteristics that make it suitable for specific and potential applications, such as crusher machines in the cement industry, wings on aircraft, propellers in wind power plants, and specific diesel engine components. All of these applications are subjected to forces in the form of vibration.

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