Natural Fiber-based Composite Materials to Enhance the Vibration Damping in Automotive Bonnet

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***Abstract*—Vibrations play a major role in causing fatigue and shortening the lifespan of automotive parts. These vibrations mainly stem from the vehicle's design and construction, road conditions, and driving behaviors, which together hinder the performance of various parts. It is crucial to reduce vibrations in key safety components to ensure the overall performance of the vehicle. The quest for enhanced vehicle performance has resulted in a growing interest in utilizing natural fibers to improve vibration damping properties in automotive applications.**

This study explores the potential of natural fibers as an innovative approach to boost the damping efficiency of automotive bonnets. Materials sourced from natural fibers such as flax, jute, hemp, and cotton offer several advantages over synthetic alternatives, including a lower environmental footprint, cost-effectiveness, and greater sustainability. The bonnet's essential low vibration damping areas were identified through FRF tests. Natural fibers like cotton, jute, hemp, and flax were affixed to the inner surfaces of the identified low damping zones on the bonnet. The maximum improvement in the vibration damping ratio reached 110.5% for the bonnet, demonstrating a notable enhancement. This novel method offers a sustainable and cost-effective substitute for the traditional synthetic materials commonly used in the automotive sector.

***Keywords*— Bonnet, Natural Fiber, Composite Materials, Vibration Damping**

I. Introduction

Effectively managing vibration is crucial in both industrial environments and research endeavors. Numerous industries utilize synthetic rubbers to mitigate Noise, Vibration, and Harshness (NVH), thereby enhancing performance and reducing maintenance requirements. Nevertheless, it has been observed that the production of synthetic materials significantly contributes to air, water, and noise pollution. As a result, natural fibers, which are completely recyclable, abundantly available, and derived from organic sources, have been investigated as feasible alternatives for this research initiative. The demand for research and development of natural fibers is increasing daily, particularly given the challenges associated with creating environmentally sustainable composites in the automotive sector. This study aimed to enhance damping properties while ensuring environmental sustainability by employing polymer matrix composites that incorporate natural fibers.

Fasana et al. [1] performed a study on material characterization with an emphasis on damping and composite materials. They evaluated two specimens: one that integrated carbon fiber-reinforced polymer with a damping material, and another that did not include such a material. The damping materials employed were HHZ 9578 and SUT 9609. The elastic modulus and damping parameters were determined through experimental testing utilizing the Obrest Testing Method, which consists of exciting a cantilever beam at approximately 20% of its length with an electromagnetic non-contact exciter across a frequency range of up to 2000 Hz. The materials were tested at temperatures from -20 °C to 60 °C in increments of 100 °C to cover various climatic conditions. Results were averaged over three specimens across five configurations, which included one structural base beam, two damped one-side beams, and two sandwich beams. The findings indicated that even a thin layer of this material can significantly improve vibration damping, offering a feasible solution for noise, vibration, and harshness (NVH) challenges.

Stanciu MD et al. [2] conducted an experimental investigation to explore the dynamic behavior of a door panel made from composite materials, specifically polypropylene and lignocellulose. The structure of the vehicle door was subjected to dynamic forces resulting from the actions of opening and closing. The velocities and accelerations experienced during these impacts were analyzed using experimental methods alongside finite element method (FEM) simulations. Significant findings from the experimental tests included the variation in acceleration upon impact, as recorded by an accelerometer, the duration of the door's closure, and the displacement of specific points on the door panel. These parameters were documented and analyzed to provide insights into the performance of the composite materials under impact conditions. Various scenarios were investigated to assess the effects of the gasket and pawl on the recorded acceleration during impact. Different push force values were applied through a spring and trigger mechanism, and the resulting data were compared with FEM results. The displacements of points on the door panel were determined by evaluating the difference between the displacement of the inner point and that of the outer point after the impact. The door's metal structure, being fundamentally more rigid, shows minimal deformation. At lower speeds, the impact acceleration is affected by the sealing and door stopper, while the presence of the pawl amplifies impact accelerations with slight forces applied to the door. In contrast, when substantial force is applied to the door, the pawl does not affect the impact acceleration values or closing times, which are exclusively determined by the quality of the seal. The displacements of the door panel points are dictated by the difference between the displacements of the inner and outer points after the impact. The rigidity of the metal structure of the door leads to insignificant deformation. The experimental results reveal that the displacements at point 1 and point 2 are influenced by the force applied to the spring, with point 1 showing an average displacement of 0.73 mm and point 2 showing an average displacement of 0.34 mm.

C. Alves et al. [3] performed a Life Cycle Assessment (LCA) to assess the viability of using jute fibers as an alternative to glass fibers in reinforcing composite materials for automotive structural components. The case study involving the buggy demonstrated that jute fiber composites are the most effective method for enhancing the environmental performance of enclosures, thus improving the overall environmental impact of the vehicle. The integration of jute fibers resulted in a decrease in vehicle weight, which led to reduced fuel consumption; however, the LCA uncovered some overlooked consequences related to the manufacturing and disposal of bonnets, particularly regarding the logistics of transporting jute fibers and the recycling processes for bonnets. In addition to the standard inputs usually considered in product design, this analysis provided the design team with valuable insights that supported informed decision-making. The team maintained close collaboration with suppliers to optimize the logistics of jute fiber utilization and concentrated on minimizing pollution during the more detrimental phases of production to mitigate potential environmental impacts. Ultimately, this case study represents a significant initial step towards the sustainability of the Brazilian buggy industry, serving as a potential model for other manufacturers seeking to develop more environmentally friendly vehicles and enhancing consumer awareness about the necessity of adopting greener consumption practices.

S. Prabhakarana et al. [4] performed a study on the sound and vibration damping properties of flax-reinforced composites. The findings indicated that flax fiber reinforced composites have a superior sound absorption coefficient, showing increases of 21.42% and 25% when compared to glass fiber reinforced composites at both high (2000 Hz) and low (100 Hz) frequency ranges. Furthermore, these composites exhibit a 51.03% enhancement in vibration damping in comparison to their glass fiber equivalents. Flax fiber reinforced composites also demonstrate notable specific flexural strength and specific flexural modulus. The sound absorption coefficient of the samples was measured using an impedance tube tester over a frequency range of 100-2000 Hz. The flexural strength and modulus were evaluated according to the ASTM D 790 standard, while the damping factor was determined using the free vibration method as specified by ASTM standard E756. The exploration of natural fiber-reinforced composite components for automotive applications was spearheaded by S.C.R. Furtado et al. [5], who conducted a comprehensive study on vegetable fiber composites, focusing on glass fiber-reinforced polyester and jute fiber-reinforced polyester for testing. This research involved evaluating the natural frequencies and fiber damping coefficients by employing two identical buggy bonnets, with the results being analyzed comparatively. Dynamic tests were conducted using BRUEL and KJAER software, demonstrating that precise characterization of such materials can be accomplished through non-destructive techniques. It was noted that jute fiber is lighter than glass fiber and exhibits superior damping properties, suggesting that jute fiber may serve as a feasible alternative for noise, vibration, and harshness (NVH) applications. Furthermore, Kil HG et al. [6] investigated the efficacy of the Energy Flow Finite Element Method (EFFEM), which is based on Energy Flow Analysis (EFA), in forecasting the vibration of an automobile door within the medium to high frequency spectrum. The anticipated frequency response function of the door was juxtaposed with experimental findings, validating EFFEM's utility as a predictive instrument for structural vibration. EFFEM is adept at simulating the intensity and energy levels of structural vibrations in assembled structures at medium-to-high frequencies. The experimental study aimed at quantifying the structural loss factors and input power of the automobile door, which were later employed as input parameters for EFFEM. The frequency response functions were documented across the surface of the door, and the comparison between experimental and predicted outcomes illustrated EFFEM's dependability in forecasting structural vibrations. The paper suggests that subsequent research should focus on assessing the intensity of structural vibrations utilizing EFFEM.

Anas et al. [7] investigated how the type and density of crosslinks affect the energy dissipation mechanisms in natural rubber compounds. Their results showed that increasing the crosslink density in natural rubber leads to a reduction in heat generation within these materials. It was found that polysulfidic linkages provide superior vibration damping compared to monosulfidic or disulfidic linkages. Rajesh et al. [8] conducted a study on the application of banana and sisal natural fibers in beam structures, revealing a notable damping factor of 0.1527 at a frequency of 472 Hz for banana fiber. Additionally, Etaati et al. [9] examined the damping properties of hemp fiber-reinforced polypropylene composites at various fiber percentages (from 0 to 60 wt%) and frequency ranges (from 1 to 200 Hz). The composite containing 30 wt% oil hemp fiber exhibited the highest damping capacity among all the composites tested, indicating its potential as a vibration damping material in automotive applications. Current research is concentrating on evaluating the performance of natural fibers and polymer composites that incorporate natural fibers as reinforcement in automotive applications, with the goal of enhancing structural integrity and reducing vibrations [10-11].

Y. Aboobucker Parvez et al. [12] presented a thorough examination of the existing research regarding damping in fiber-reinforced composites. It addresses different types of fibers, encompassing both natural and synthetic varieties, and their effects on the mechanical and damping characteristics of composite materials. The authors underscore the mechanisms of energy dissipation within these composites and the factors that affect damping performance, including fiber orientation, length, and content. The review stresses the significance of optimizing these parameters to improve the vibration damping capabilities of composites for a range of applications, especially in the automotive and aerospace sectors. The paper concludes by pinpointing gaps in the current research and proposing future avenues for enhancing the understanding of damping behavior in fiber-reinforced composites.

Nikhil, K.V. et al. [13] examined the vibration characteristics and damping factor of coir fiber-reinforced polyester composites using experimental methods. The authors concentrate on how different fiber content affects the mechanical properties and damping performance of the composites. The findings demonstrate that the addition of coir fibers significantly improves the damping factor, with the optimal fiber content resulting in better vibration absorption.

This study offers important insights into the connection between fiber reinforcement and damping behavior, indicating that coir fiber composites can be effectively employed in applications that require vibration control.

Kumar, K. S. et al. [14] investigated the combined effects of fiber length and content on the free vibration and damping behavior of natural fiber-reinforced polyester composite beams. The authors perform experiments to evaluate how changes in these parameters affect the mechanical properties and damping performance of the composites. The results indicate that both fiber length and content are crucial in determining the vibration characteristics, with optimal combinations leading to improved damping behavior. This study highlights the significance of customizing fiber properties to achieve the desired performance outcomes in natural fiber composites, making them appropriate for a range of engineering applications.

In a recent study carried out by the same author [15], the vibration damping characteristics of steel plates were assessed by integrating various layers of natural fibers, including jute, hemp, banana, and flax. The findings indicated that flax was the most efficient in vibration damping, with jute ranking as the second most effective natural fiber. Furthermore, in a separate study [16], the researcher aimed to enhance the vibration damping properties of a passenger vehicle door panel. By pinpointing areas with both low and high vibration damping, the study incorporated natural fibers such as hemp, cotton, and jute fabrics into the regions exhibiting low damping. The introduction of 3 mm layers of these natural fibers led to a notable increase in the damping ratio, achieving a 30% enhancement. This finding highlights the potential of natural fibers as a sustainable and eco-friendly alternative to synthetic materials in the automotive sector to mitigate vibration-related challenges.

The previously mentioned research acts as a robust indicator of the efficacy of viscoelastic composite materials and their application as damping agents in automotive contexts. Additionally, this research suggests that natural fibers demonstrate outstanding performance as damping materials. The main objective of this study is to assess the damping performance and cost-effectiveness of materials based on natural fibers in relation to synthetic materials.

II. Defining Low Damping Area on Bonnet

The Bonnet was divided into sections measuring 15cm by 15cm, as shown in Figure 1. A corresponding Excel representation of the Bonnet was also developed, as illustrated in Figure 2.

The experimental testing was conducted on the bonnet to assess its vibration response utilizing an FFT analyzer. The testing configuration includes a Brüel & Kjaer four-channel FFT analyzer, an accelerometer, and a hammer with a force capacity of 1000 lbf. Frequency response function (FRF) data was captured on the bonnet and analyzed up to 900 Hz with a frequency resolution of 1 Hz. The FRF and Coherence graphs were generated at each point identified on the bonnet. The average FRF and coherence were computed from three reliable impact readings, which helped to reduce the standard deviation during measurements. The FRF serves as an essential tool for the dynamic analysis of structures, while coherence indicates the extent to which the output of the FRF is influenced by its input. A coherence value close to 1 signifies high quality of the FRF data, indicating a strong relationship between the two inputs. Three reliable measurements were taken, achieving a coherence level of 0.9 or greater. Similarly, three consistent readings were recorded for each of the 45 grid points on the bonnet. The natural frequencies associated with these 45 points are presented in Figure 3.

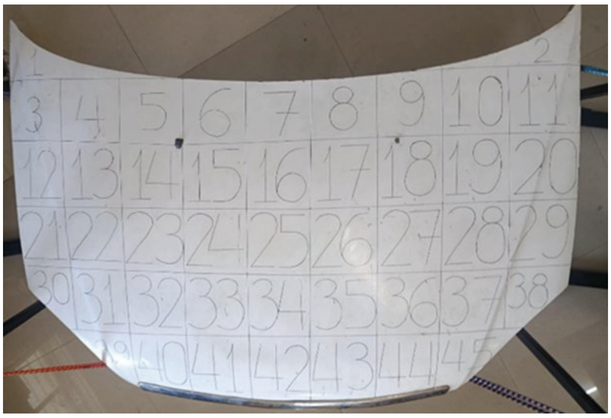

Fig. 1. 45 grid point drawn on the selected bonnet.

1								2
3	4	5	6	7	8	9	10	11
12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29
30	31	32	33	34	35	36	37	38
	39	40	41	42	43	44	45	

Fig. 2. Excel representation of the selected bonnet.

195								146
176	196	133	196	187	157	143	194	198
195	198	193	179	161	192	194	199	165
181	177	194	194	180	191	192	193	193
197	194	194	197	192	194	194	194	194
	198	185	196	180	197	182	193	

Fig. 3. Natural frequency of each grid point.

Analysis of Figure 3 reveals that the natural frequencies at most locations show a certain level of variation. Nevertheless, the central section of the bonnet exhibits remarkable uniformity within the frequency range of 190-200 Hz. This consistency can be linked to the structural ribs and the differing thickness of the roof near its corners and edges. As a result, the primary emphasis of the bonnet is on the central section, particularly at points 13 to 19, 22 to 28, and 31 to 37. In this central zone, seventeen out of twenty-one points are situated within the 190-200 Hz frequency range. Thus, it can be inferred that the natural frequency of the bonnet's central area, marked in red in Figure 1(d), is defined by the absence of ribs and a consistent thickness, unlike the bonnet's edges. This uniformity is likely responsible for the stable natural frequency observed in the 190-200 Hz range. The average natural frequency for the seventeen points in this central section is determined to be 192 Hz. Given the lack of ribbing in this area, it has been recognized as a key focus for future research aimed at improving damping. The vibration damping percentage for the 17 points in the central region has been evaluated and is represented in the Excel chart shown in Figure 4. The average vibration damping value for these seventeen points is calculated to be 1.53. Therefore, it can be concluded that the baseline vibration damping (in the absence of any material) for the central section of the bonnet is 1.53%.

2.23	1.61			1.84	1.85	1.6
	1.09	1.9		1.27	1.42	1.66
1.57	1.27	1.16	1.07	1.31	1.27	1.91

Fig. 4. Vibration damping percentage of each grid point highlighted in center area.

III. NATURAL FIBER BASED MATERIALS ON THE AREA OF INTEREST OF THE BONNET

In this research, the decision was made to utilize natural fiber-based materials to enhance the vibration damping capabilities of the bonnet in comparison to synthetic materials. Natural fibers contribute to vibration damping by means of energy dissipation mechanisms, which include internal friction and viscoelastic behavior. Additionally, their structural features, such as twist and crimp, further improve their capacity to absorb sound and effectively diminish vibrations.

Concerning the sustainability of natural fiber-based materials, these materials present numerous advantages in automotive applications, such as being biodegradable, recyclable, and sourced from renewable resources. Their application can greatly decrease vehicle weight and related emissions, while also improving energy efficiency and fostering eco-friendly manufacturing practices. Despite these benefits, natural fiber composites in automotive settings encounter challenges from moisture, temperature variations, and UV exposure, which may result in the deterioration of their mechanical properties. Recognizing these factors is essential for enhancing their long-term durability and performance under diverse conditions. Nevertheless, natural fiber materials can be utilized in areas of the vehicle that experience minimal exposure to moisture, temperature changes, and UV radiation, such as the roof, doors, and foot floors, among others.

To improve the vibration damping characteristics, the same materials—specifically Cotton, Jute, Hemp, and Flax—were selected.

The density of cotton fibers generally measures approximately 1.54 g/cm³. The tensile strength of cotton fiber can differ based on the specific grade and processing technique, but it usually falls within the range of 300 to 600 MPa. The grams per square meter (GSM) of the cotton fabric chosen for this study is 110 GSM. The density of jute fiber is usually around 1.3 g/cm³. The tensile strength of jute fiber varies according to the specific grade and processing method, typically ranging from 300 to 800 MPa. The GSM of the jute fabric selected for this study is 250 GSM. The density of hemp fiber is typically about 1.5 g/cm³. The tensile strength of hemp fiber generally ranges from 550 to 900 MPa, depending on the specific variety and processing methods. The GSM of the hemp fabric chosen for this study is 200 GSM. Flax Fiber: The density of flax fiber is generally around 1.5 g/cm³. The tensile strength of flax fiber varies based on the specific grade and processing method, typically ranging from 400 to 1000 MPa. The GSM of the flax fabric selected for this study is 170 GSM.

The bonnet was noted to have a weight of 15 Kg and a thickness of 5 mm, as measured at the corners with a Vernier Caliper. It was subsequently established that a maximum thickness of 3 mm for these natural fiber materials would be tested. To accomplish this, four layers of 0.25 mm thick cotton sheets were bonded together to create a 1 mm thick cotton layer. Similarly, two layers of 0.5 mm thick jute, three layers of 0.33 mm thick hemp, and layers of flax measuring 0.34 mm were combined to form 1 mm thick layers of each respective material. Sheets with thicknesses of 1 mm, 2 mm, and 3 mm for each material were produced and then applied to the bonnet for assessment. The materials were accurately cut to fit the non-ribbed central section of the bonnet and adhered accordingly. Figures 5, 6, 7, and 8 depict the application of Cotton, Jute, Hemp, and Flax positioned behind the bonnet, respectively.

Fig. 5. Cotton material cutout affixed in the area of interest.

Fig. 6. Jute material cutout affixed in the area of interest.

Fig. 7. Hemp material cutout affixed in the area of interest.

Fig. 8. Flax material cutout affixed in the area of interest.

IV. RESULTS AND DISCUSSION

Frequency Response Function (FRF) tests were performed on the bonnet for each material at thicknesses of 1mm, 2mm, and 3mm. The average of three reliable readings, with a coherence level greater than 0.9, was documented for all seventeen points across all materials and thicknesses. Figure 9 demonstrates the percentage improvement in damping for each material at each thickness, relative to the baseline condition (without any material).

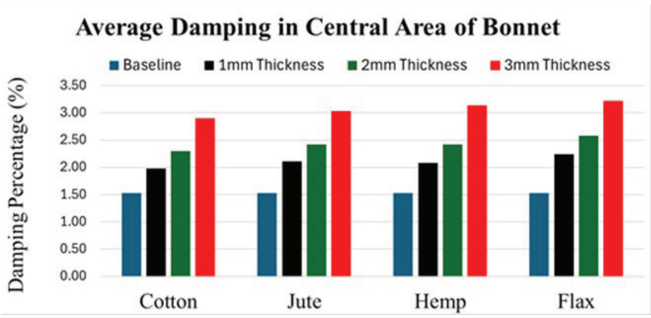

Fig. 9. Comparison of the vibration damping improvement of the materials with 1mm, 2mm and 3mm thickness on the bonnet.

Table 1 indicates a notable increase in damping following the application of 1 mm of material, while the enhancement with 2 mm thickness does not significantly exceed that of 1 mm. However, a marked improvement is again observed with the addition of a 3 mm layer. Additionally, it was noted that the natural frequency decreases from 192 Hz to 186 Hz after the introduction of 3 mm of material, which is minimal. The alterations in the system's dynamic response will be attributed to the increased mass and damping characteristics of the fibers. Nevertheless, this will improve comfort by minimizing vibrations in automotive engineering.

Furthermore, the application of 1 mm, 2 mm, and 3 mm layers of cotton results in vibration damping improvements of 29.4%, 50.3%, and 89% respectively, compared to the baseline damping. Each layer of jute shows superior performance, achieving vibration damping improvements of 37.9%, 58.2%, and 98% with the 1 mm, 2 mm, and 3 mm layers respectively. In contrast, hemp slightly underperforms compared to jute, with a 35.9% improvement in vibration damping at the 1 mm layer, while matching jute's performance at the 2 mm thickness with a 58.2% improvement. Hemp attains the second-best damping performance with a 3 mm layer, resulting in a 105.2% improvement in vibration damping. Flax surpasses all other materials, exhibiting enhancements in vibration damping of 46.4%, 68.6%, and 110.5% for thicknesses of 1 mm, 2 mm, and 3 mm, respectively.

The total cost incurred for obtaining the materials required to achieve a thickness of 3mm for each fiber type was ₹750 for Cotton, ₹600 for Jute, ₹2700 for Hemp, and ₹210 for Flax. The corresponding weights of each fiber at this thickness are 0.89 Kg for Cotton, 0.83 Kg for Jute, 0.63 Kg for Hemp, and 0.71 Kg for Flax. Therefore, the use of natural fiber materials in automotive applications presents numerous benefits, such as decreased costs, lighter weight, and environmentally sustainable manufacturing methods. These materials exhibit a high strength-to-weight ratio, are biodegradable, and can improve vehicle performance by enhancing sound and vibration dampening.

TABLE I. THE AVERAGE VALUES OF NATURAL FREQUENCY (FN), DAMPING FACTOR (Q), AND PERCENTAGE DAMPING RATIO (Ξ) WERE ASSESSED AT A TOTAL OF 17 SELECTED POINTS WITHIN THE AREA OF INTEREST.

Test Configuration		Fn (Hz)	Q	ξ (%)
Baseline		192.00	34.57	1.53
Cotton	1mm	189.00	26.13	1.98
	2mm	188.00	22.30	2.30
	3mm	186.00	17.66	2.90
Jute	1mm	189.00	24.33	2.11
	2mm	188.00	21.00	2.42
	3mm	186.00	16.95	3.03
Hemp	1mm	189.00	24.58	2.08
	2mm	188.00	20.89	2.42
	3mm	187.00	16.73	3.14
Flax	1mm	190.00	22.66	2.24
	2mm	188.00	19.68	2.58
	3mm	186.00	16.13	3.22

V. CONLCUSION

This study investigated the vibration damping performance of a car bonnet. The bonnet was suspended in a free-free arrangement using bungee cords to conduct the

Frequency Response Function (FRF) tests. Data from specific local points were analyzed to determine the bonnet's overall response. Consequently, regions with both low and high vibration damping properties were identified on the bonnet. It was noted that there is considerable potential to improve vibration damping to reach the levels observed in the high damping areas of the bonnet.

Natural fibers including Cotton, Jute, Hemp, and Flax were chosen as materials to improve vibration damping. These materials were applied to the inner surfaces of the identified low damping regions of the bonnet. The results indicated a favorable correlation between the thickness of the damping layers and the enhancement of the damping ratio, with layers measuring 1 mm, 2 mm, and 3 mm undergoing testing. Notably, the 3 mm layer exhibited a superior vibration damping effect in comparison to the other layers. The highest enhancement in the vibration damping ratio was recorded at 110.5% for the bonnet with the application of flax, representing a notable improvement. This innovative approach offers an environmentally friendly and sustainable substitute for the synthetic materials frequently used in the automotive industry at present.

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