Structural damping properties of natural porous material of jute felt.

R. Kumar[1] and A. R. Mohanty[1]

[1]Department of Mechanical Engineering, Indian Institute of Technology,

Kharagpur, India

Abstract

Most sound-absorbing and damping materials are synthetic which are harmful to health of living beings and environment [1]. Worldwide with researcher's growing interest in utilizing porous material as the sound-absorbing and structural damping material, the focus is on developing natural, biodegradable, and recyclable porous material. Jute is a natural lignin cellulose-based material with great potential as a sound-absorbing material, as shown in studies [2-6]. Fatima et al. [2] showed that the low-density jute composite was a better sound-absorbing material than the high-density jute composite material. Bansod et al. [3] measured the acoustical properties of jute felt and jute fiber using experimental, analytical, and numerical methods. They extended this work to use jute with micro-perforated panel (MPP) and air gap to boost the sound absorption in the low-frequency region [4]. The work included the measurement of non-acoustic properties to be used in the Transfer Matrix Method (TMM) to characterize the sound absorption of jute with MPP and air gap considering different combinations. Later in [5], jute's acoustic properties are measured using the impedance tube transfer method. The measured property is then used to inverse characterize the porous material model using Particle Swarm Optimization (PSO) to obtain the non-acoustic parameter, i.e., airflow resistivity, porosity, thermal and viscous characteristics length of the jute felt. Mohanty et al. [6] used the jute as sound-absorbing material in a domestic clothes dryer's casing panel to reduce the noise emitting from the motor, belt, and casing of the dryer by around 6 dB. The noise produced in the dryer is the combination of the vibrations of the running motor, motor and belt, casing panel. The application of jute such as this and similar cases like metro rail, rail wagon, and aircraft where the vibrating structure is causing noise, utilizes the porous material damping property of the material. Hence it is necessary to characterize the structural damping property of the jute for its multipurpose use. Therefore, a need to review the work of structural damping material of porous material is required to choose the proper damping model to characterize its damping property. Wahl and Bolton [7] considered the thin Euler Beam panel in space and time domain under line force. The beam's governing equation is double Fourier transformed in space and time domain to obtain the wavenumber and frequency domain's governing equation. Then Discrete Fourier Transform (DFT) is used to find the panel's velocity in wavenumber frequency domain response considering the boundary conditions. Inverse Discrete Fourier transform (IDFT) is then used in the space domain to get the panel's spatial response. The work also presents the precautions to utilize the Fast Fourier transform (FFT) method to capture the spatial resolution correctly. They extended this work in [8] to evaluate the panel's temporal response by again Inverse Discrete Fourier transform method (IDFT). Xue et al. in [9-10] further used this work to assess the structural damping in terms of power dissipation and structural loss factor for the unconstrained and constrained infinite panel loaded with limp, bonded, and unbonded poroelastic material. The authors used this to design the microstructure of porous material for optimum damping to be obtained at a particular frequency. Further, Xue et al. in [11] did a parametric study based on the macroscopic properties (thickness, airflow resistivity, and bulk density) of glass fiber and polymeric fiber based on the damping model introduced in [9]. From the literature review, it is clear that jute is an excellent sound-absorbing material. If the jute shows potential as the structural damping material, it could save weight and cost. Therefore, this study's purpose is to use the natural material as structural damping material that is already proven sound-absorbing, cheap, and biodegradable material. It is a naturally porous material that can reduce the adverse effect by utilizing synthetic material environments. It is to be noted here that the methodology adopted for this study is from [9, 10] for the constrained and unconstrained panel for the damping by the jute felt as a limp porous layer. The present work is grouped in two. In group 1. (a), we study the jute's effect with an unconstrained panel. This includes evaluating the panel vibration response with or

without increasing the thickness and bulk density simultaneously of the jute felt on the panel's vibration response, power dissipation within the porous layer, and structural damping loss factor. (b) The effect of the panel material (Aluminum and Stainless steel, which is generally used in the metro and rail wagons[11]) and thickness is studied as expressed in normalized power dissipation within a porous layer. c) Effect of porosity on normalized power dissipation within the jute felt. In the second Group 2, the panel's velocity and structural damping loss factors are evaluated for the jute felt. The Aluminium and Stainless steel panels density is 2100 and 7955 $\mathrm{kg/m^3}$, the modulus of elasticity is 70 GPa and 203 GPa, the Poisson ratio is 0.33 and 0.27, and the loss coefficient is 0.003 and 0.00125. It is here to be noted that jute's macroscopic properties are taken from the previous work [5]. The jute felt of thickness 4, 8, and 10 mm with a bulk density of 76.13, 116.4, and 148.3 $\mathrm{kg/m^3}$, airflow resistivity of 32751, 20803, and 28629 $\mathrm{Ns/m^4}$, the tortuosity of 1.05 for each, the thermal characteristics length of 50, 67.45, and 50 µm and viscous characteristics length 129.85, 130, and 130 µm.

This study evaluates the damping effect for an unconstrained and constrained panel subjected to line force applied in Group 1 and Group 2, respectively. In Group 1, the unconstrained panel's velocity response vs. space is evaluated with and without the jute felt to compare its effect. The result shows that jute's use in the panel reduces the velocity response. As the thickness and bulk density of the jute felt increases, the panel's velocity response is reduced considerably faster before the critical frequency. The normalized power dissipation in the jute layer increases with the increase of thickness of the Jute layer. The difference between the first peak to the first trough of normalized power dissipation reduces, i.e., the normalized power dissipation increases at the trough, leading to more uniform power dissipation within the layer. The use of the Jute layer shows an appreciable damping loss factor. Increasing bulk density and thickness increases the damping loss factor at lower frequencies. The result also shows the panel thickness's effect; as the panel thickness is reduced, the critical frequency increases, but the difference between the peak and trough of the normalized power dissipation is decreasing, i.e., more uniform. The result also shows that the porosity variation has no significant effect on normalized power dissipation in the jute material before its critical frequency. Using the Stainless steel and Aluminium panel, the normalized power dissipation and damping loss factor in a porous layer are compared with the panel's same thickness. In the second group, the panel's velocity and structural damping loss factors are evaluated for the jute felt. The results are promising to utilize the jute felt as a damping material. Thus it paves the purpose of this study to use jute as a natural material for structural damping. Therefore Jute Felt could be utilized as sound-absorbing as well as structural damping material without causing harm to the environment.

References

[1] Asdrubali, Francesco; D'Alessandro, Francesco; Schiavoni, Samuele (2015). *A review of unconventional sustainable building insulation materials. Sustainable Materials and Technologies, 4(), 1–17.* doi:10.1016/j.susmat.2015.05.002

[2] S. Fatima; A.R. Mohanty (2011). *Acoustical and fire-retardant properties of jute composite materials. , 72(2-3), 108–114.* doi:10.1016/j.apacoust.2010.10.005

[3] Bansod, Pritesh Vishwasrao; Mittal, Tushar; Mohanty, Amiya Ranjan (2016). *Study on the Acoustical Properties of Natural Jute Material by Theoretical and Experimental Methods for Building Acoustics Applications. Acoustics Australia, 44(3), 457–472.* doi:10.1007/s40857-016-0073-4

[4] Bansod, Pritesh V; Teja, T Sai; Mohanty, Amiya R (2017). *Improvement of the sound absorption performance of Jute felt-based sound absorbers using micro-perforated panels. Journal of Low Frequency Noise, Vibration and Active Control, 36(4), 376–398.* doi:10.1177/1461348417744307

[5] Bansod, P.V.; Mohanty, A.R. (2016). *Inverse acoustical characterization of natural jute sound absorbing material by the particle swarm optimization method. Applied Acoustics, 112(), 41–52.* doi:10.1016/j.apacoust.2016.05.011

[6] Mohanty, A.R. & Fatima, Shahab. (2015). Noise Control Using Green Materials. Sound and Vibration Magazine. 49.

[7] T.J. Wahl and J.S. Bolton, “The Use of the Discrete Fourier Transform to Calculate the Spatial Response of Damped Panels,” Proceedings of the Acoustics '90, 1990 Spring Conference of the Institute of Acoustics (U.K.), published in Proceedings of the Institute of Acoustics, Vol. 12 (1), pp. 945-952, 1990, https://docs.lib.purdue.edu/herrick/123.

[8] T. J. Wahl and J. S. Bolton, *The Use of the Discrete Fourier Transform to Calculate the Spatial and Temporal Response of Line-Driven, Layer-wise Homogeneous Acoustically Loaded Panels,* Journal of the Acoustical Society of America, Vol. 92, pp. 1473-1488, 1992 .

[9] Xue, Yutong; Bolton, J. Stuart (2018). *Microstructure design of lightweight fibrous material acting as a layered damper for a vibrating stiff panel. The Journal of the Acoustical Society of America, 143(6), 3254–3265.* doi:10.1121/1.5038255

[10]Xue, Yutong; Bolton, J. Stuart; Herdtle, Thomas; Lee, Seungkyu; Gerdes, Ronald W. (2019). *Structural damping by lightweight poro-elastic media. Journal of Sound and Vibration, (), 114866–.* doi:10.1016/j.jsv.2019.114866

[11] Yutong Xue, J. Stuart Bolton, Thomas Herdtle, Seungkyu Lee and Ronald W. Gerdes, “A Comparison between Glass Fibers and Polymeric Fibers when Serving as a Structural Damping

Medium for Fuselage-like Structures," *Proceedings of InterNoise 2018*, Chicago, Paper 1478, August 2018, https://docs.lib.purdue.edu/herrick/179.

[12] Government of India ministry of urban development, a report of the committee on "*standardization and indigenization of metro railways, systems and sub-systems.* November 2013