INVESTIGATION OF SOUND ABSORPTION AND VIBRATION DAMPING OF FLAX FIBRE COMPOSITES

Le Quan Ngoc Tran[1], Kede Huang[2], Abhishek Vishwanath Rammohan[2], Wern Sze Teo[1], Heow Pueh Lee[2]

[1]Singapore Institute of Manufacturing Technology, 71 Nanyang Drive, Singapore 638075

[2]Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576

Keywords: Flax fibre composites, acoustic behaviour, vibration damping, thermoplastics

Abstract

Sound absorption, sound transmission and vibration damping behaviour of flax fibre composites were investigated by impedance tube test, acoustic box and modal damping analysis respectively. The characterisations were performed on both unidirectional and cross-ply flax fibre thermoplastic composites. In the sound tests, sound absorption coefficient and sound transmission loss of the composites at a large range of sound frequencies were determined. Modal analysis with an impact hammer test was carried out to extract the dynamic properties, namely the natural frequency, damping ratio and mode shape of the composites. The results showed that sound absorption properties of the flax composite are better at high frequency above 1500 Hz, and have high sound transmission loss at low frequency corresponding to their stiffness. The fibre orientation in the composites has little effect on sound absorption, but gives substantial influences on vibration damping.

1. Introduction

In recent years, natural fibres including flax, hemp, and jute have received increasing interests for use in high performance composite materials. The fibres have good mechanical properties, low density and environmental-friendly nature. In addition, natural fibres are composite themselves, which have hierarchical structure and multi-level morphology. This structure of the fibres may offer their composite good damping properties.

Recent work on damping properties of flax fibre composites was reported by Duc et al [1,2], which shows the flax composites have better damping properties at room temperature than those of carbon and glass fibre reinforced composites. The vibration damping of flax composites is at least 2.5 time higher than for carbon fibre composites. The investigation was carried out based on dynamic mechanical analysis of the composites between different flax fibre architecture and various matrix systems. Natural fibres and their composites have been known as good materials for noise control and sound absorption, especially for applications in car interiors [3]. Prabhakaran et al. [4] reported that the sound absorption coefficient of flax fibre composites was 21-25% higher than that of glass fibre reinforced composites at frequency level from 100-2000 Hz. Koenig et al [5] have also shown that fleeces reinforced polypropylene composites, commonly used to produce car interiors, have excellent acoustical performance when combined with other natural fibres such as flax, hemp and kenaf.

Excerpt from ISBN 978-3-00-053387-7

In this study, sound absorption, transmission and vibration damping behaviour of flax fibre thermoplastic composites were investigated. The tests were performed on both unidirectional and cross-ply flax fibre composites and sandwich between the composite and foam. In the acoustic characterisations, sound absorption coefficient and sound transmission loss of the materials are determined using a standing wave impedance tube and acoustic box. For the vibration, modal analysis with an impact hammer was used to extract the dynamic properties, namely the natural frequency, damping ratio and mode shape of the composites.

2. Experimental

2.1. Materials

Unidirectional (UD) flax fibre tape provided by by Lineo (Belgium) was used for the production of UD and cross-ply (CP) composites. Non-woven flax mat was supplied by EcoTechnilin (France). Polymer matrix was polypropylene (PP) supplied by Lotte Chemical Titan (Malaysia). For the sandwich, PET foam from 3A Composites was used as core.

2.2. Composite preparation

Flax fibre reinforced polypropylene composites were prepared using compression moulding technique. A stack of flax fibre mats and PP films with a designed sequence was placed in between two aluminium plates. A steel frame was used to surround the stack to control the thickness of produced composite. The whole set-up was then placed into a hot press for composite fabrication under processing parameters of 190^{o}C at 20 bar pressure and for 15 minutes. After that the mould was cooled down at a cooling rate of 15^{o}C/min until room temperature under the same pressure.

Sandwich between the flax fibre composite and the foam core was prepared by bonding the composite skins onto foam core using thermal bonding at temperature of 200 ^{o}C at the skin-core interface.

2.2. Sound absorption and transmission tests

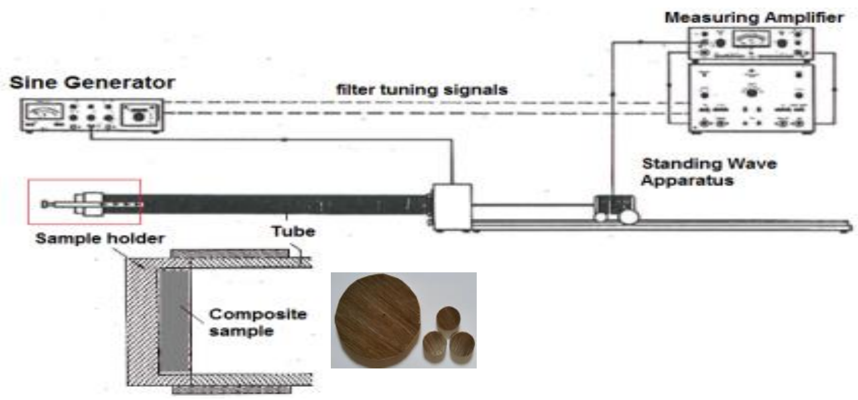


Figure 1. Standing wave apparatus and composite samples in sound absorption test

The sound absorption coefficients of the samples were measured using the standing wave apparatus type 4002. This test set-up includes a loudspeaker situated at one end of an acoustically rigid tube and the sample material to be tested is placed at the other end. A plane sound wave is then generated by the loudspeaker in the tube towards the sample. The wave will be partially reflected by the sample, resulting in a standing wave due to the superposition of the incident and reflected waves. The microphone probe, connected to the microphone carriage, can be moved inside the tube to detect the alternating maximum amplitude and minimum amplitude of the sound pressure. The ratio of the maximum sound pressure to minimum sound pressure is known as the standing wave ratio (SWR)

Excerpt from ISBN 978-3-00-053387-7

which is translated into sound absorption coefficient accordingly. Two tubes with the diameter of 102.5 mm and 32.5 mm were used for measurements in the frequency range from 100-1600 Hz and 800-6300 Hz respectively. Figure 1 shows the two set-up and test samples.

For the sound transmission test, an acoustic box was designed to measure sound pressure level (SPL), as shown in Figure 2. One end of the acoustic box is open for the test composite sample to be clamped, while the opposite end is mounted with a woofer connected to a 15 MHz Keysight Function Generator. The SPL on either side of the specimen is recorded by two microphones that is mounted at the centre of the box. The software Sonoscout is used for data acquisition. The sound STL is determined by taking the difference between the SPLs measured on both side of the composite panel when subjected to a pure tone plane waves. The frequency range investigated was 100 to 2500 Hz at 100 Hz intervals.

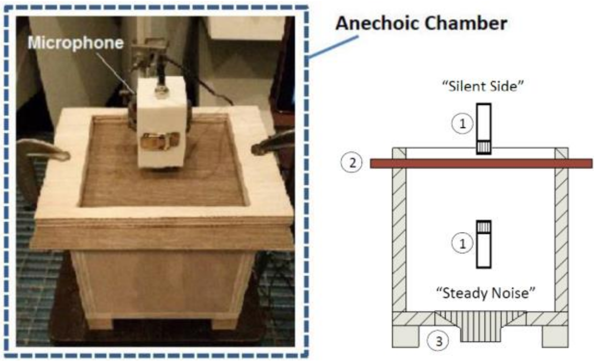


Figure 2. Sound transmission measurement set-up (microphone-1, composite sample-2 and woofer-3)

2.3. Modal analysis

Vibration analysis of the composites was carried out using modal analysis with an impact hammer to extract the dynamic properties, namely the natural frequency, damping ratio and mode shapes. Square samples were divided into 25 grid points as shown in Figure 3 to measure the frequency response corresponding to each point. The accelerometer was mounted onto the sample at point 1 by using an adhesive wax so that it would have the same vibration. Point 1 to Point 25 of the sample were then each excited by the impact hammer, with averaging done for 4 excitations at each point. A load cell was attached to the end of the hammer to record the force applied. A spectrum analyser linked to a computer computed the frequency response functions for all the points by using the post processing modal software, m+p International's SO Analyser. The results will were analysed using the Advanced Multiple Degree of Freedom Wizard to identify the dynamic properties and display the mode shapes in animation.

Both the UD and CP flax/PP composite were characterized. The samples were subjected to three different boundary conditions; free-free-free-free (FFFF) boundary condition on all four sides by suspending the sample with two strings, FFFF boundary condition on all four sides by placing the sample on a soft sponge foam, and clamp-free-free-free (CFFF) boundary condition by clamping one side of the sample (Figure 3).

Excerpt from ISBN 978-3-00-053387-7

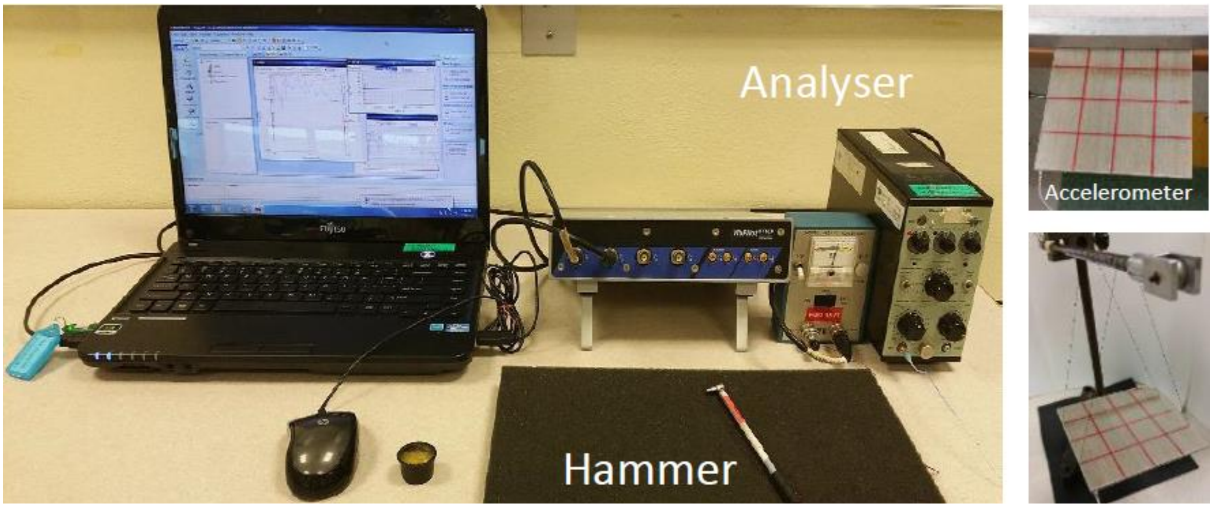


Figure 3. Modal analysis of composite samples

3. Results and discussion

3.1. Sound absorption properties of flax fibre composites

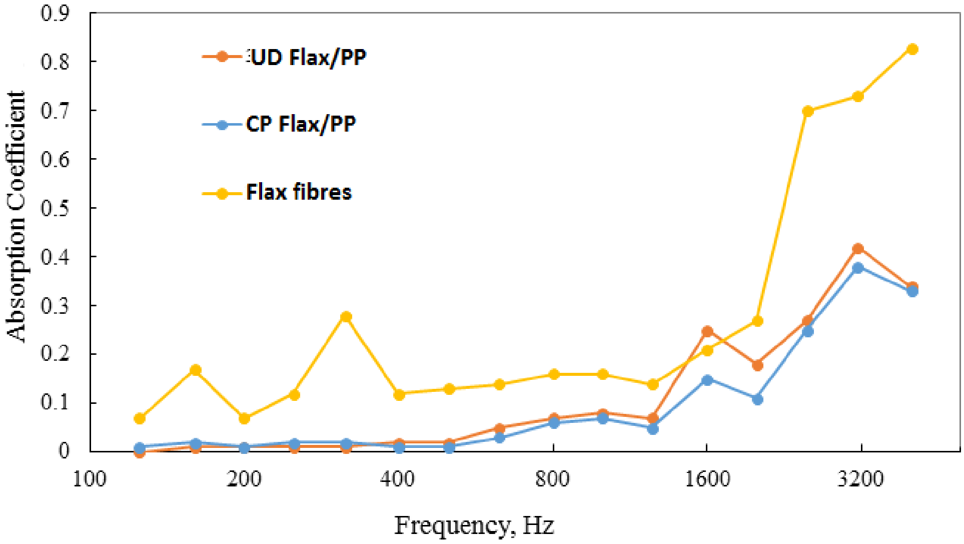


Figure 4. Sound absorption coefficent of flax fibre composites and pure flax fibres

Figure 4 presents the sound absorption coefficient of UD and CP flax/PP composites (V_f around 32%) and the pure flax fibres with the same amount used for the composites. It can be seen that the flax fibre has better sound absorption than its composites. The fibre bundle has higher porosity as compared to the composites, which allows the sound waves to propagate into the fibres to dissipate more sound energy. Both UD and CP flax/PP composites have low sound absorption at low frequency ranging 100 to 1250 Hz. There is a significant increase of the absorption coefficient from the frequency higher than 1500 Hz and it is approximately 40% at 3150 Hz. It can be explained that the short wave length of high frequency leads to longer propagation path within the composites.

3.2. Sound transmission

Excerpt from ISBN 978-3-00-053387-7

Sound transmission loss (STL) of several flax/PP composite systems, flax fibres and sandwich of flax composite and PET foam in the frequency range of 100 to 2500 Hz is shown in Figure 5. It can be seen that the composites have higher STL as compared to the flax fibres. This result is expected due to the fact that the flax fibres have higher porosity which assists sound wave propagation through the material. The composites behave similarly across the range of frequency, in which there are four main regions as reported by Daniel [6]. In the low frequency region, the STL is governed by the stiffness of materials. Therefore, the STL at 100Hz of the composites is substantially higher than that of the flax fibre and the UD composite with higher fibre volume fraction (higher stiffness) performs better as compared to the lower fibre volume fraction composite.

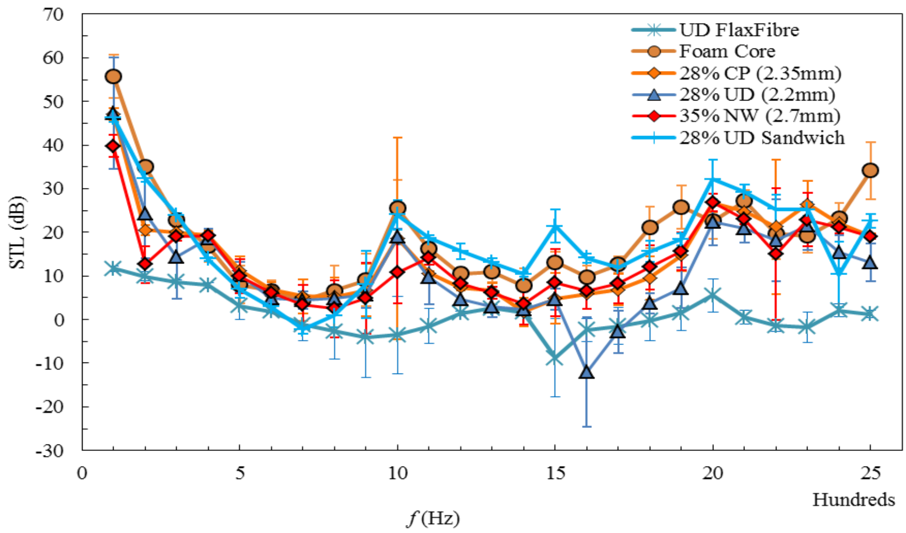


Figure 5. Sound transmission loss (STL) as a function of applied sound frequency for different composites, flax fibre and sandwich.

The resonance frequency of the composites is found at the second region with sound frequency in the range of 400 to 900 Hz, where there appears to be a minimum in STL. In the third region with the frequency from 900 to 1600 Hz, the STL follows mass law. It can be seen that the STL of the sandwich between the flax PP composite and foam core is higher than that of the flax PP composites due to higher material thickness.

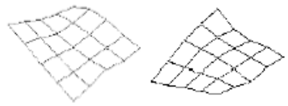
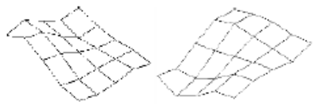
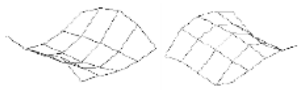
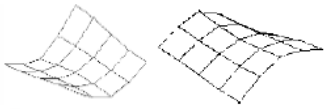
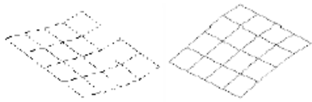
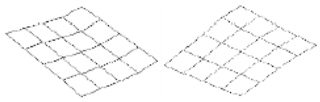
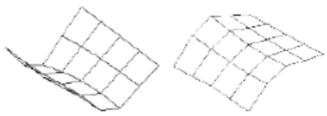
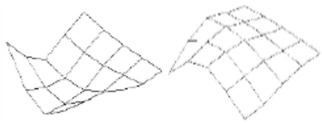
3.3. Vibration damping

Table 1 presents natural frequency, damping ratio and mode shape at different modes and at three boundary conditions for the UD and CP flax PP composites. The natural frequency of the composites depends on composite stiffness which is affected by fibre orientation and architecture. The stiffer composites have higher natural frequency. In this regard, the UD composite is more anisotropic behaviour than the CP composite, and has low stiffness in fibre transverse direction. In general, the natural frequency of the CP composite was found to be higher than that of UD composite at each mode.

Energy dissipation in composites is induced by many different processes, such as the viscoelastic behaviour of the matrix and fibres, damping at the fibre-matrix interface, and damping due to damages like matrix cracks. Damping is greater in UD composites perhaps due to the larger energy dissipation along the fibre-matrix interface that run perpendicular to the fibre direction. The CP composite has fibres in both directions and it is possible that damping due to energy dissipation along the fibres are more dominant, which could lead to lower total energy dissipition as compared to the UD composites.

Excerpt from ISBN 978-3-00-053387-7

Table 1. Natural frequency (f), damping ratio (D) and mode shape of UD and CP flax fibre PP composites

		V_f 28% UD (2.2 mm)	V_f 28% CP (2.2 mm)
Foam Setup **Free-Free-Free-Free Boundary Condition**	**Mode 1**	 f = 43.77 Hz, D = 41.85%	 f = 96.28 Hz, D = 16.09%
	Mode 3	 f = 258.33 Hz, D = 6.31%	 f = 355.73 Hz, D = 3.47%
String Setup **Free-Free-Free-Free Boundary Condition**	**Mode 1**	 f = 50.04 Hz, D = 18.80%	 f = 36.40 Hz, D = 16.68%
	Mode 3	 f = 251.16 Hz, D = 3.72%	 f = 358.00 Hz, D =3.01%
Clamped Setup **Clamped-Free-Free-Free Boundary Condition**	**Mode 1**	 f = 32.70 Hz, D = 4.59%	 f = 56.32 Hz, D = 4.56%
	Mode 3	 f = 234.13 Hz, D = 4.131%	 f = 335.03 Hz, D = 3.43%

3. Conclusions

The sound and vibration damping properties of flax fibre polypropylene have been investigated in this study. The composite has high sound absorption coefficient at high frequency from 1500 Hz and above. For sound transmission, the sound transmission loss of the composites increases with the increasing materials stiffness. In vibration analysis, the natural frequency of the composites was also highly dependent on composite stiffness, while the damping ratio is dominant by the matrix properties and the fibre-matrix interface due to high energy dissipation mechanism.

Acknowledgments

The authors would like to acknowledge the financial support from the Agency for Science, Technology and Research (A*STAR) under the Science and Engineering Research Council (SERC) grant number 1426400041.

Excerpt from ISBN 978-3-00-053387-7

References

[1] F. Duc, P.E. Bourban, C.J.G. Plummer, J.-A.E. Månson, Damping of thermoset and thermoplastic flax fibre composites, *Composites Part A: Applied Science and Manufacturing*, 64:115-123, 2014.

[2] F. Duc, P.E. Bourban, J.-A.E. Månson, The role of twist and crimp on the vibration behaviour of flax fibre composites, *Composites Science and Technology*, 102:94-99, 2014.

[3] G. Thilagavathi, E. Pradeep, T. Kannaian, L. Sasikala. Development of Natural Fiber Nonwovens for Application as Car Interiors for Noise Control. *Journal of Industrial Textiles*;39(3):267-278, 2010.

[4] S. Prabhakaran, V. Krishnaraj, M. Senthil kumar, R. Zitoune, Sound and Vibration Damping Properties of Flax Fiber Reinforced Composites, *Procedia Engineering*, 97: 573-581, 2014.

[5] C.R. Koenig, D.H. Muller, and K.D. Thoben. Acoustical Parameters of Automotive Interiors using Hybrid Fleeces basing on natural fibres. *Acoustics conference*. *Paris*, June, 2008.

[6] R.R., Daniel. The Science and Application of Acoustics. AIP Press 2000.

Excerpt from ISBN 978-3-00-053387-7