# THE EFFECT OF CORE HEIGHT ON THE VIBRO-ACOUSTIC BEHAVIOR OF FIBRE REINFORCED CORES

G. Petrone[1*], S. Rao[2], S. De Rosa[1], B. R. Mace[2], D. Bhattacharyya[2]

[1]*PASTA-Lab: Laboratory for Promoting experiences in Aeronautical STructures and Acoustics, Department of Aerospace Engineering, University of Naples "Federico II", Via Claudio 21, 80125 Naples (Italy)*
[2] *Centre for Advanced Composite Materials, Department of Mechanical Engineering, The University of Auckland, Private Bag 92019 Auckland (New Zealand)*
**giuseppe.petrone@unina.it*

**Keywords:** honeycomb, natural fibres, acoustics

## Abstract
In view of the current state of environmental awareness, the need for reduced emissions and strict government legislation, natural fibre thermoplastic sandwich panels were manufactured using continuous unidirectional and short random flax fibre reinforced polyethylene honeycomb cores. The influence of the reinforcement type in the composite core and of the core height on acoustic property of the panels was investigated using a standing wave apparatus. Measurements were taken in third octave bands in the frequency range from 100*Hz* to 4*kHz*. The panels exhibited absorption coefficients of about ~0.5 at higher frequencies and 0.3 at lower frequencies. The absorption at lower frequencies was mainly due to the fibrous arrangement behind the resonating faceplate but at higher frequencies this effect became negligible and the viscoelastic core governed the absorption.

## 1 Introduction
In the last few years, the production of polymer composites reinforced with natural fibres (green composites) has substantially increased, especially in sectors such as the automotive, leisure and furniture industry, where their reduced cost and higher bio-degradability have offered several incentives to their use. In a recent advancement, natural fibre composites have been transformed into honeycomb cores for sandwich panels, extending their application from predominantly non-structural components to load-bearing structures. Hence, with this recent advancement, the application of green composites can be extended to load-bearing structural materials in various engineering fields, especially within the aircraft, automotive and civil sectors.
In the aforementioned industries, such panels could potentially find application in interior paneling and some secondary load bearing structures such as, cabin/wall dividers, foot rests, seat backing, door trims and galleys. Therefore, apart from structural competence, human comfort within such environments will also play an important role in their acceptance. Though the quality associated with person's comfort is not unique, the effect of noise and vibration can clearly be identified as a primary factor causing discomfort. There are several sources of vibrations and noise, for example in aircraft it could be due to the boundary layer flow, acoustic excitation of the fuselage from the propeller, structure borne noise due to engine vibration or flow distortion over the wing [1]; in buildings, it could be due to traffic,

domestic appliances, and in automotive due to engine noise, external traffic etc. Hence, to enhance human comfort, all unwanted noise and vibration must be attenuated. Noise attenuation methods may involve active and/or passive controls. In active noise control, the reduction of the internal sound field is obtained by installing many microphones and speakers within the room to cancel the noise; other methods involve modification of acoustic transmission properties by installing actuators and sensors near the source of the vibration. Passive noise control includes structural modifications [2] or damping augmentation [3] by using natural carpets or tuned panels to absorb vibrations at certain frequencies. However, noise attenuation remains a complicated topic and obtaining attenuation over wide range of frequency is difficult, it is usually achieved as combination of both methods. In this study, honeycomb cores for sandwich panels were manufactured from natural fibre reinforced composites and fibrous arrangement within the core was used to absorb sound. The acoustic performance of the sandwich panels can be categorized by sound transmission loss (TL) and sound absorption. The former relates to the application of the panel as a sound barrier, preventing the sound to pass through it and the latter relates to the ability of the panel to absorb the incident sound. In many cases, a panel exhibiting good sound absorbance will also be a good sound barrier; however, the panels can be manufactured to cater to the acoustic requirements. In this study, the sound absorption properties of the panels have been investigated using standing wave apparatus. As sandwich panels exhibit sharp absorbance peaks at a certain frequency when the sound waves are incident on the faceplate, the property has been investigated at different core heights in view of obtaining optimum absorption by balancing the density of the fibrous media within them. Several studies have been conducted to investigate acoustic performance of sandwich structures, for example, Land and Dym [4] have investigated an optimal acoustic design of sandwich panels by fixing one physical variable and changing the others, concluding that insulation is directly proportional to its mass and inversely to stiffness, Ashby and coworkers [5] have tested aluminum foam cores in an impedance tube and have obtained absorption coefficient of 0.9 at mid and high frequencies when it is crushed to 10% of its original height owing to the bursting of the cell walls. In recent years research has been focussed on fibre reinforced core with the intention of satisfying both weight and sound insulation/vibration suppression requirements. For effective sound absorption, fibrous media has been used for decades and the principle behind this absorption is that when the sound wave strikes the fibrous material, the pressure due to sound vibrates the air contained in the fine air space in the fibrous assembly, creating a frictional resistance between the fibres and the air gaps. The incident sound energy is consumed in overcoming this frictional resistance, which is dissipated as heat into the surroundings. The absorption in this fibre media is also dependent on the fibre size, fineness of the fibre, fibre packing within the space and the frequency of the sound wave. However, in this study, transmission of sound waves to the cavity behind the facings, containing coarse wool fibres due to resonance of the facings plays a key role in sound absorption.

## 2 Materials and manufacturing

The main materials may be described as follows:

- Linear Low Density PolyEthylene (LLDPE) films was used as matrix material;
- Unidirectional flax fibre mat (UD180 - C003) of 180 g/m$^2$ from Lineo, Belgium and random fibre mat of ~200g/m$^2$ from Sachsen-Leinen GmbH, Germany were used as reinforcement;
- Glass fibre-PP tape, Plytron™ was used as facing material.
- The cores were manufactured using film-stacking process where the dry flax mat and LLDPE films were interleaved and laid between half hexagonal matched-dies with heating and cooling ability.

- The matched-die was heated to ~170°C after closing the mould at 500mm/s, constant forming pressure of ~0.5MPa was maintained during the heating cycle for consolidation and the formed part was cooled within the die to avoid spring-back. The half-hexagonal corrugations were laser cut to 20mm and 40mm, which were then assembled and bonded using ultrasonic methods.
- Coarse wool, 10% weight of the sandwich panels was manually inserted after the cores were manufactured. Plytron™ facings - consolidated under vacuum in an oven maintained at 185° - were then bonded to the cores using ultrasonic method to make sandwich panels, Fig. 1.

All the panels were designed to fail in core shear and more about ultrasonic bonding conditions and sandwich panel design can be found in [6].

(a) (b)

**Figure 1.** Sandwich panel manufacturing (a) Matched-die used for forming (b) Sandwich panels for acoustic test (diameters of 100mm and 30mm)

## 3 Testing

The sound absorption coefficients of the honeycomb core sandwich panels with Glass-PP facings and Flax-PE core were determined using a Brüel & Kjaer standing plane wave impedance tube. The sample is placed at the end of a tube exposed to a pure tone produced by a loud speaker. The phase interference between the waves in the pipe, which are incident upon and reflected from the test sample, results in the formation of a standing wave pattern in the pipe. Impedance tubes of diameter 100mm, a length of 1.0m and diameter 30mm, length 500mm were used to determine the absorption coefficient of samples from 100*Hz* - 1.6*kHz* and 1.6*kHz* - 4*kHz* respectively. The upper frequency is limited to those where only plane waves can propagate in the impedance tube ($f$<0.586 $c/d$, being $c$ is the speed of sound and $d$ the tube diameter). Two reinforcement configurations of core, long/unidirectional and short/random fibres at two different core heights 20mm and 40mm were tried.

| Material property | | Value |
|---|---|---|
| Fibre volume fraction | $v_f$ | 0.3 |
| Tensile Modulus | $E_{11}$ | 10 GPa |
| | $E_{22}$ | 0.9 GPa |
| Tensile strength | $\sigma_{max}$ | 110 MPa |
| Poisson ratio | $\upsilon_{12}$ | 0.24 |
| Compressive modulus | $\sigma_{max}$ | 2 GPa |
| In plane shear strength | | 16 MPa |
| Sheet Density | $\rho$ | 1100 kg/m$^3$ |

**Table 1.** Mechanical properties of Flax-PE sheet

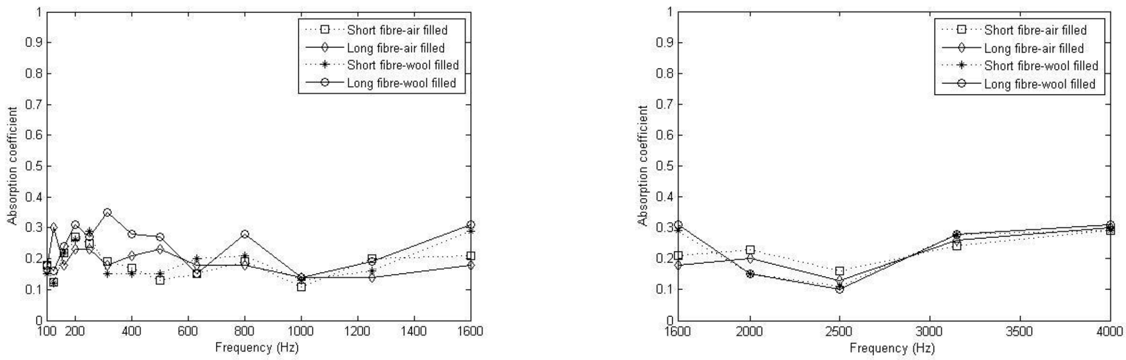
For the core material, tensile tests were conducted using ASTM standard test method D3039 [7]. The tests were conducted using an Instron testing machine (Model 5567) at a crosshead speed of 2 mm/min. Compressive and in plane shear tests were carried out again the Instron testing machine as per ASTM D6641 and ASTM D4255 specifications respectively [8,9].

## 4 Results

Tests measurements were taken at 1/3 octave from 100*Hz* to 4*kHz*. Two types of cores: one with short random fibre and the other with continuous unidirectional reinforcement, both at two different core heights were tested. The absorption coefficient has been analysed with respect to the type of reinforcement and the core height.

### *4.1 Effect of reinforcement type on sound absorption*

Sound absorption coefficients for honeycomb cores with short random and continuous unidirectional fibre reinforcement are depicted in Fig. 2 which shows the behaviour of the curves of two configurations of sandwich panels with core height of 20mm at low, intermediate and high frequencies. In the low frequency range (<500Hz), continuous fibre reinforced LLDPE core exhibits sound absorption coefficient, peaking between 0.3-0.4, Fig.2 (a), outperforming the short fibre reinforced cores whose maximum absorption is ~0.3. However, as the frequency approaches intermediate-high frequency, at 1.6kHz, the absorption occurs irrespective of the type of fibre reinforcement within the cell wall and is dominated by the fibrous arrangement behind the faceplate. At higher frequencies (3kHz-4kHz) when the facings start to vibrate independently about their neutral axis, the absorption appears to occur irrespective of the fibrous arrangement behind the faceplates or reinforcement type, which may be due to the presence of damped viscoelastic matrix behind stiff facings.

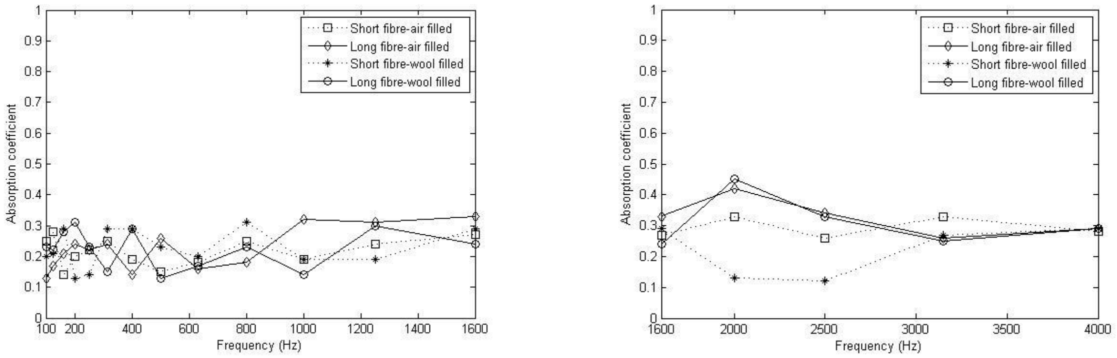



(a) (b)

**Figure 2.** Sound absorption coefficients for honeycomb cores of 20mm height at (a) low-intermediate (b) imtermediate-high frequencies

### *4.1 Effect of core height on sound absorption*

Sound absorption coefficients for honeycomb cores with short random and continuous unidirectional fibre reinforcement, shown in Fig. 3, gives the behaviour of the curves of two configurations of sandwich panels with core height of 40mm. It is evident from Fig.3 (a) that the absorption coefficient trend seem to be similar to those of 20mm in height, meaning that the core height plays little role in sound absorption at low-intermediate frequencies, exhibiting similar absorptions as those of 20mm height. However, at higher frequencies of 2kHz, the absorption coefficient reaches to 0.5 as compared to 0.2 when cores of 20mm core height were used. Absorption coefficient of 0.5 compares to a reduction of about 3dB in sound level.




(a) (b)

**Figure 3.** Sound absorption coefficients for honeycomb cores of 40mm height at (a) low-intermediate (b) imtermediate-high frequencies

The sound absorption at lower frequencies appears to be due to the presence of fibrous wool arrangement behind the facings, similar to those of 20mm heights. However, in Fig. 3(b), the jump in absorption coefficient to 0.45 is irrespective of the fibrous loading behind the facings, which is again due to the presence of viscoelastic honeycomb core behind the stiff facings. The increase in absorption coefficients from 0.2 to 0.4 when the core heights were changed might be due to the availability of larger cell wall height, which would in effect alter its damping effect. The intention of this study was to understand the sound absorption behavior of a resonant sandwich panel with natural fibre reinforced polymeric cores at different core heights and type of reinforcement. A resonant panel vibrates at certain frequencies and transmits the sound wave to the cavity behind it, which in this case is the core filled with wool fibres allowing the sound waves to be absorbed by the porous medium. Such resonance of the faceplate in this study occurs at low-intermediate frequencies (upto1*kHz*) and the absorption increases particularly at 1*kHz* due to the presence of wool fibres.

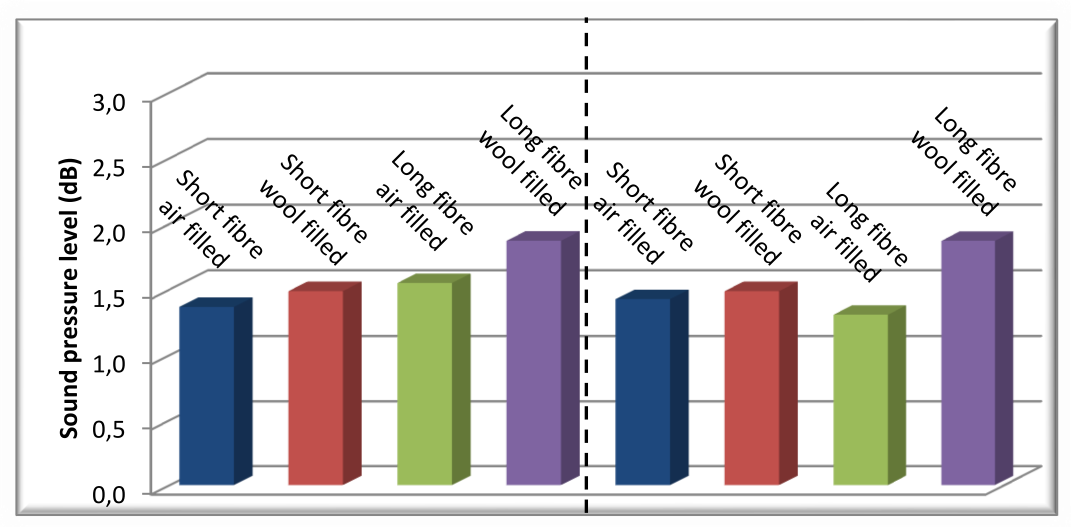



**Figure 4.** Average sound pressure level (SPL) for different core configurations between 100Hz -500Hz (bars on the left of the dotted line corresponds to core height of 20mm, right corresponds to 40mm)

In Fig. 4 the average sound pressure level (SPL), that is a logarithmic measure of the effective sound pressure of a sound relative to a reference value, of all core configurations tested at low

frequency shows that a maximum of 1.87dB reduction can be obtained at 315*Hz* when cores are reinforced with continuous unidirectional fibres and are of 20mm in height and filled with wool fibres. However, when the core height is increased to 40mm, absorption at 315*Hz* remain the same meaning that core height for low frequency range has no effect.
In Fig. 5, the average SPL for different core configurations between 500Hz – 4kHz have been shown. A maximum of 2.51dB reduction is obtained with cores having continuous fibre reinforcement and of greater heights. All the core configurations at lower core heights exhibit similar adsorptions. An ideal core material for sound attenuation will have high mass, low shear stiffness and high compressive stiffness. However, in our case, this can be compensated to certain extent as a viscoelastic material has been used as a matrix in the core. Coarse wool accounting to 10% weight of the sandwich panel was used as fibrous media behind the facings to absorb sound, which appears to be only necessary at lower frequencies.

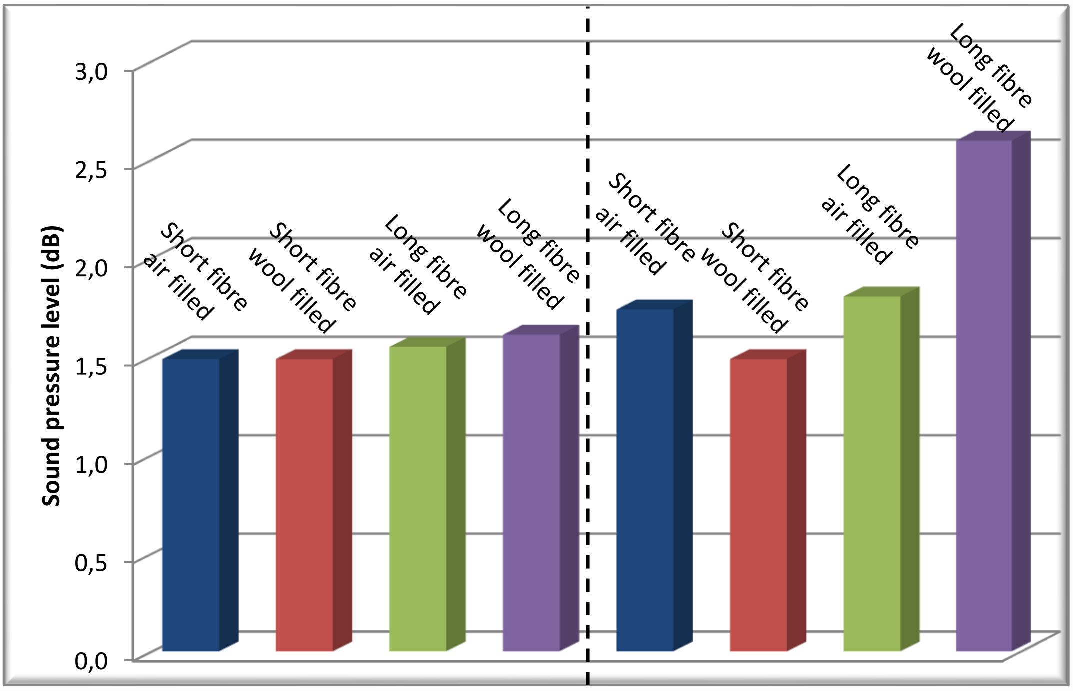



**Figure 5.** Average sound pressure level (SPL) for different core configurations between 500Hz – 4kHz (bars on the left of the dotted line corresponds to core height of 20mm, right corresponds to 40mm)

## 5 Summary

In view of reducing undesirable impact on the environment, recyclable thermoplastic honeycomb cores were produced from natural fibre composites. Continuous unidirectional and short random flax fibres were used as reinforcement within LLDPE matrix. The composites exhibited an improvement >100% in mechanical properties compared to the matrix material. The sound absorption tests carried out in an impedance tube setup revealed absorption coefficient of ~0.5 at the higher frequency of 2*kHz*. Sound absorption at lower frequencies was dominated by the fibrous arrangement behind the resonating faceplate but at higher frequency it was mainly due to the viscoelastic core and the effect of wool fibres in the core cavities was negligible. Hence, weight reduction in the panels could be anticipated for high frequency absorption only while an increase of only 10% in weight of the panels would achieve sound reductions of 2-3dB at wider frequency range.

**Acknowledgments**

This work was originated during the stay of the first author in New Zealand at the University of Auckland. The visit was under the partial support of SUPERPANELS project, *Strengthening and Upholding the Performances of the new Engineered Research PANELS,* funded by European Union (PEOPLE-MARIE CURIE ACTIONS, FP7-PEOPLE-2009-IRSES).

**References**

[1] Mixson J. S., Powell C. A. *Review of Recent Research on Interior Noise of Propeller Aircraft* in *AIAA/NASA 9th Aeroacoustics Conference*, Williamsburg, Virginia, (1984).
[2] Bhat R. B., Sobieszczanski J., Mixson J. S. *Reduction of Aircraft Cabin Noise by Fuselage Structural Optimization* in *Noisexpo*, Chicago, Illinois, (1977).
[3] Halvorsen W. G., Emborg U. *Interior Noise Control of the Saab 340 Aircraft* in *General Aviation Aircraft Meeting and Exposition*, Wichita, Kansas, (1989).
[4] Lang M.A., Dym C.L. Optimal Acoustic Design of Sandwich Panels. *The Journal of the Acoustical Society of America*, **57**, pp. 1481-1487 (1975).
[5] Ashby M. F., Evans A. G., Fleck N. A., Gibson L. J., Hutchinson J. W., Wadley H. N. G.. *Sound absorption and vibration suppression* in “Metal Foams: A Design Guide”, Butterworth-Heinemann, Burlington, pp. 171-180 (2000).
[6] Rao S., Jayaraman K., Bhattacharyya D. Short fibre reinforced sandwich cores and panels: processing and evaluation. *Composites Part A: Applied Science and Manufacturing*, **42**, pp. 1236-1246 (2011).
[7] ASTM D 3039. *Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials* (2008).
[8] ASTM D 6641. *Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a combined Loading Compression (CLC) Text Fixture* (2009).
[9] ASTM D 4255. *Standard Test Method for In-Plane Shear Properties of Polymer Matrix Composite Materials by the Rail Shear Method* (2007).