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Identification of uncertainty levels of acoustic properties of biocomposites under different mounting conditions in impedance tube tests

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Impedance tube method is widely used to measure acoustic properties of materials. Although this method yields reliable acoustic properties for soft textured materials, uncertainty levels of measured acoustic properties for hard materials, including biocomposites, can be quite large, mainly due to uncertain mounting conditions. Here, the effects of mounting conditions on the acoustic properties of biocomposites in an impedance tube are investigated. First, nominally identical biocomposite samples with a diameter equal to the inner diameter of impedance tube are manufactured and their acoustic properties are determined. As hard materials practically cause fitting problems in the impedance tube, the diameters of samples are reduced, as in practice, by small amounts and acoustic properties of modified samples are determined. Furthermore, in order to match the diameters of samples to the inner diameter of impedance tube, different materials such as tape, petroleum jelly and cotton are applied around samples to close the air gap between the samples and the tube's inner wall. All the results are compared and the uncertainty levels caused by different mounting conditions on the acoustic properties of biocomposites are identified. The results show that the transmission loss measurements are dramatically affected by the mounting conditions while the sound absorption conditions are less sensitive to the mounting conditions. The deviations in the measured transmission loss levels are highest for the samples with tape and wax (10-15 dB). On the other hand, the deviations in the measured sound absorption coefficients are highest for the samples with cotton and tape (1-2%).

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1. INTRODUCTION

The use of engineering products made from natural fiber based composite materials is steadily increasing in recent years[1-3]. Accordingly, some studies have been conducted to investigate the potential of using natural fibers and their composites in practical applications[3-6]. As the acoustic and mechanical properties of these natural materials should be assessed before considering them in practical applications, there have been many studies to identify the acoustic properties of these materials[7-12]. The impedance tube method is widely used to determine the acoustic properties, such as sound absorption coefficients (SACs) and transmission losses (TLs), of materials as described in the standards[13-15]. Although the acoustic properties for soft textured materials can be obtained using the impedance tube method with high accuracy, the measured acoustic properties for hard materials, including biocomposites, can show huge variations.

Some studies have been made to investigate the effects of sample sizes[16], circumferential edge constraint[17], the air gap around the sample[18] and the calibration of microphones[19]. It should be noted that the importance of sample preparation and mounting have been investigated in the past[20-21]. An experimental study has been conducted to investigate the effects of tube dimensions on measurement of acoustic properties in an impedance tube[22]. However, the uncertainty levels of the measured acoustic properties of hard samples, including biocomposite samples, under different mounting conditions using an impedance tube have not been quantified before.

In this study, the effects of mounting conditions on the identified acoustic properties of biocomposites in an impedance tube are investigated. For this purpose, nominally identical test samples with a nominal diameter equal to the inner diameter of the impedance tube (29 mm) are manufactured and their acoustic properties are determined using the impedance tube method. As the hard materials practically cause fitting problems in the impedance tube, the diameters of the test samples are reduced by different amounts (0.1-0.4 mm) and the acoustic properties of the modified test samples are determined using the impedance tube method again. As in practice, in order to match the diameters of the test samples to the inner diameter of the impedance tube, different materials such as tape, petroleum jelly and cotton are applied around the test samples to close the air gap between the samples and the tube's inner wall and the acoustic properties of the modified test samples are determined using the same testing method. Repeatability of the tests is investigated for each test case and the results are presented both as Fast Fourier Transformation (FFT) and Octave spectrums. All the results are compared and the uncertainty levels caused by different mounting conditions on the acoustic properties of biocomposites are identified.

The results show that the transmission loss measurements are dramatically affected by the mounting conditions while the sound absorption conditions are less sensitive to the mounting conditions. The deviations in the measured transmission loss levels are highest for the samples with tape and wax (10-15 dB). On the other hand, the deviations in the measured sound absorption coefficients are highest for the samples with cotton and tape (1-2%). The deviations both in the transmission loss levels (1-2 dB) and sound absorption coefficients (<0.5%) are lowest for the samples whose diameter reduced by 0.1 and 0.2 mm. It can be said that the samples whose diameters are reduced by only 0.1 mm are quite repeatable and produce reasonable results.

2. MATERIALS AND METHODS

Luffa fiber and epoxy resin are used to manufacture bio composite plates in this study. The composite plates are cured under a pressure of 5 Bar at 85 ^{0}C for two hours. Circular test samples with a diameter of d = 29 mm and thickness of h = 20 mm are prepared using the manufactured biocomposite plates. Here, the circular samples were cut from the manufactured plates with a thickness of 20 mm using a Computerized Numerical Control (CNC) router. Based on the measured masses and volumes of the samples, the density of the samples is found to be $\rho = 891.0$ kg/m^3. The fiber/epoxy mass ratio is around 0.4 for the samples in this study. It should be stated that although the nominal diameter of the samples is approximately equal to the inner diameter of the impedance tube, the individual samples are usually pushed strongly to position the hard samples in the impedance tube in practice and this mounting method can produce some unexpected results. After the acoustic properties of these test samples (called original or unmodified samples) are measured, the diameters of the samples are reduced by 0.1 mm by grinding and the acoustic properties of these modified samples (d = 28.9 mm) are measured again. This process is repeated by reducing the diameters of the samples by 0.2, 0.3 and 0.4 mm (i.e., d = 28.8, 28.7 and 28.6 mm) in turn. In the standard for measuring the transmission loss levels of materials, it is stated that the gap between the test sample and impedance tube wall should be filled with various materials[14]. In order to investigate the effects of the gap-filling material on the identified acoustic properties of test samples, cotton, tape, petroleum jelly and wax are applied around the test samples with d = 28.6 mm and the acoustic properties of test samples are measured again. The experimental setup together with the pictures of the test samples without and with petroleum jelly, tape and wax are shown in Fig. 1.

The Brüel&Kjaer 4206 (for SACs) and 4206T (for TLs) impedance tubes, Brüel&Kjaer 4187 microphones, Brüel&Kjaer 3560C analyzer and Brüel&Kjaer 276C power amplifier are used for the acoustic measurements in this study. The measurements of both quantities are briefly explained here. For sound absorption coefficient measurements, a signal generator is used as a sound signal source and two microphones are used to measure the acoustic pressures. Normal incidence sound absorption coefficients are calculated using the tube dimensions and the measured acoustic transfer function. First, the complex valued normal incidence reflection coefficient $R(f)$ is calculated as[22]:

$$R(f) = \frac{H_{12}(f) - e^{-jks}}{e^{jks} - H_{12}(f)} e^{2jk(s+L)} \tag{1}$$

where $H_{12}(f)$ is the complex valued acoustic transfer function which is calculated from sound pressure signals p_1 (first microphone) to p_2 (second microphone), s is the distance between two microphones, L is the distance between the second microphone and the test sample and $k = 2\pi f/c$ is wave number (c: speed of the sound in the air and f: frequency). By using the normal incidence reflection coefficient, the normal incidence sound absorption coefficient is calculated via:

$$\alpha(f) = 1 - \left|R(f)\right|^2 \tag{2}$$

For transmission loss measurements, a similar setup used for sound absorption coefficient measurements is used, however additional two microphones (p_3 and p_4) are positioned between the test sample and termination this time. The expression for normal incidence transmission loss is given by[23]:

$$TL = 20\log\left|\frac{e^{jks} - H_{12}}{e^{jks} - H_{34}}\right| - 20\log\left|H_t\right| \tag{3}$$

where $H_{34}(f)$ is the complex valued acoustic transfer function which is calculated from sound pressure p_3 to p_4 and $H_t = \sqrt{|S_\mathrm{d}/S_\mathrm{u}|}$ is the ratio between upstream (S_u) and downstream (S_d) auto-spectrums.

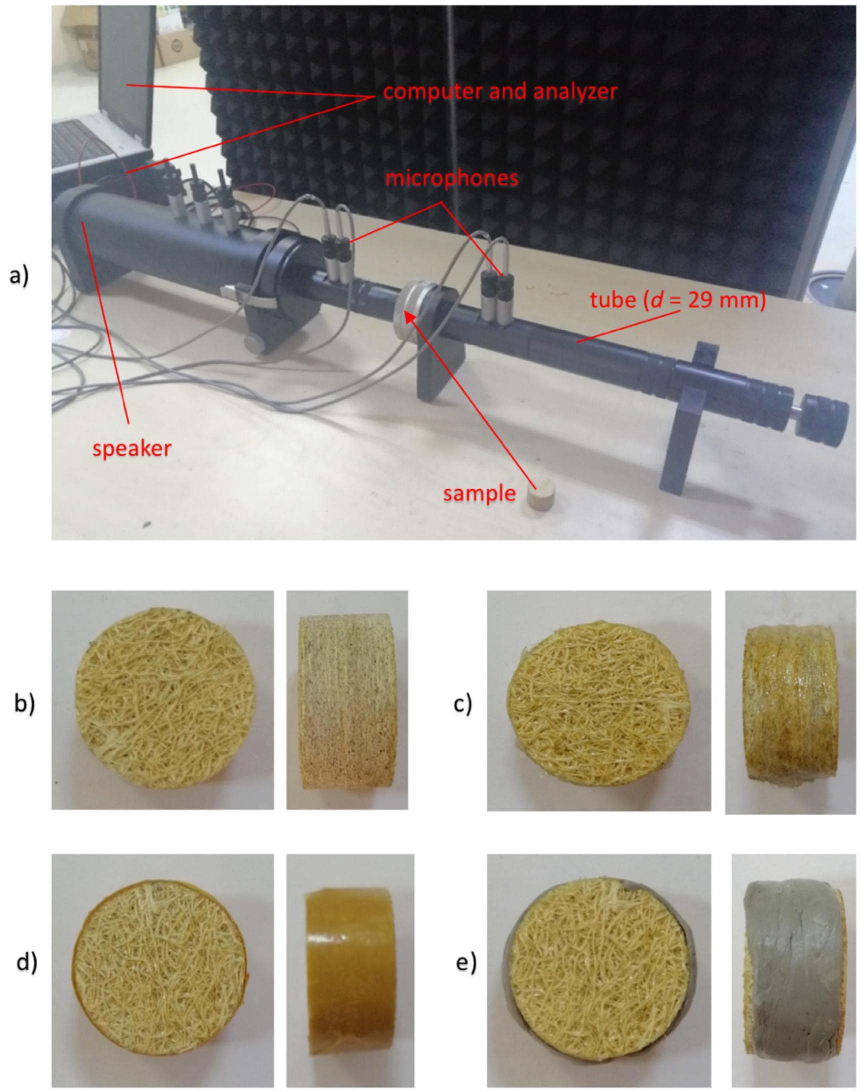

Fig. 1—Experimental test setup (a), unmodified sample (b), sample with petroleum jelly (c), sample with tape (d) and sample with wax (e).

The mass law that is commonly used to obtain a rough estimation of the TLs of test samples is given by[24]:

$$\mathrm{TL} = 10\log\left[1 + \left(\frac{\pi f \bar{\rho}}{c\rho}\right)^2\right] \tag{4}$$

where $\bar{\rho}$ is the surface density of the sample and ρ is the air density. The mass law is valid in frequency range between natural and critical frequencies. The critical frequency of a sample with a thickness of h can be predicted using[24]:

$$f_c = \frac{c^2}{2\pi}\sqrt{\frac{12\overline{\rho}(1-v^2)}{Eh^3}} \quad (5)$$

where E and v are the Young's modulus and Poisson's ratio of the sample. The Young's modulus and Poisson's ratio of the luffa composite plates with similar fiber/epoxy ratios is around 2 GPa and 0.3, respectively[10]. Hence, the critical frequency for a 20 mm thick sample using Eqn. (5) is calculated to be around 2080 Hz. The TLs of the test sample are predicted using Eqn. (4) and the results up to 2000 Hz are presented in Section 3.

3. RESULTS AND DISCUSSION

The measured normal incidence transmission loss levels for the three nominally identical test samples under four different mounting conditions (i.e., unmodified, grinded by 0.1 and 0.4 mm and with tape) are shown in Fig. 2. It is seen that transmission loss levels of the three unmodified samples (Fig. 2a) are not quite close to each other and there are arbitrary peaks at almost all frequency bands. The transmission loss levels of the samples whose diameters are reduced by 0.1 mm (Fig. 2b) are more repeatable, the number of irregular peaks is reduced compared to the original samples and the transmission loss levels are 7 dB (on average) less than those of the original samples. The transmission loss levels of the samples whose diameters are reduced by 0.4 mm (Fig. 2c) are more repeatable and the irregular peaks are almost disappeared. However, the average transmission loss levels are reduced dramatically by 25 dB (on average) compared to those of the original samples. The transmission loss levels of the samples covered with tape (Fig. 2d) are not repeatable at all and there are more undesirable peaks with high amplitudes. It seems that the tight fitting for the first case (original samples) and the fitting with the tape in the fourth case (samples with tape) produced unwanted peaks while the air gap for the third case (samples grinded by 0.4 mm) results in unrealistically low transmission loss levels. It should be noted that experimentalists generally use one of these fitting methods (i.e., the ones used to obtain the results in Figs. 2a or b or d) in practice. However, as seen, the differences between the results for different mounting conditions are huge. It is worth noting that the arbitrary peaks and dips seen in the transmission loss curves could be due to (i) the local resonances of the tape applied around the samples or the fibers of the composite sample, (ii) the noise generated by macro- or micro-slips across frictional contacts between the sample and the tube, and (iii) misalignment, etc.[17, 24-27].

The measured normal incidence sound absorption coefficients for the three nominally identical test samples under four different mounting conditions (i.e., unmodified, grinded by 0.1 and 0.4 mm and with tape) are shown in Fig. 3. It is seen that the sound absorption coefficients of the unmodified samples (Fig. 3a) and the samples grinded by 0.1 mm (Fig. 3b) are close to each other and repeatable. The measured sound absorption coefficients for the three nominally identical test samples grinded by 0.4 mm (Fig. 3c) and the samples with tape (Fig. 3d) are not repeatable and the estimated sound absorption coefficients are generally higher than the results in Figs. 3a and b. It seems that the air gap in the third case (samples grinded by 0.4 mm) results in higher sound absorption coefficients. It should also be noted that generally one of these cases (i.e., Figs. 3a or b or d) is used in practice. However, as can be seen, the differences between the results under different mounting conditions can be huge.

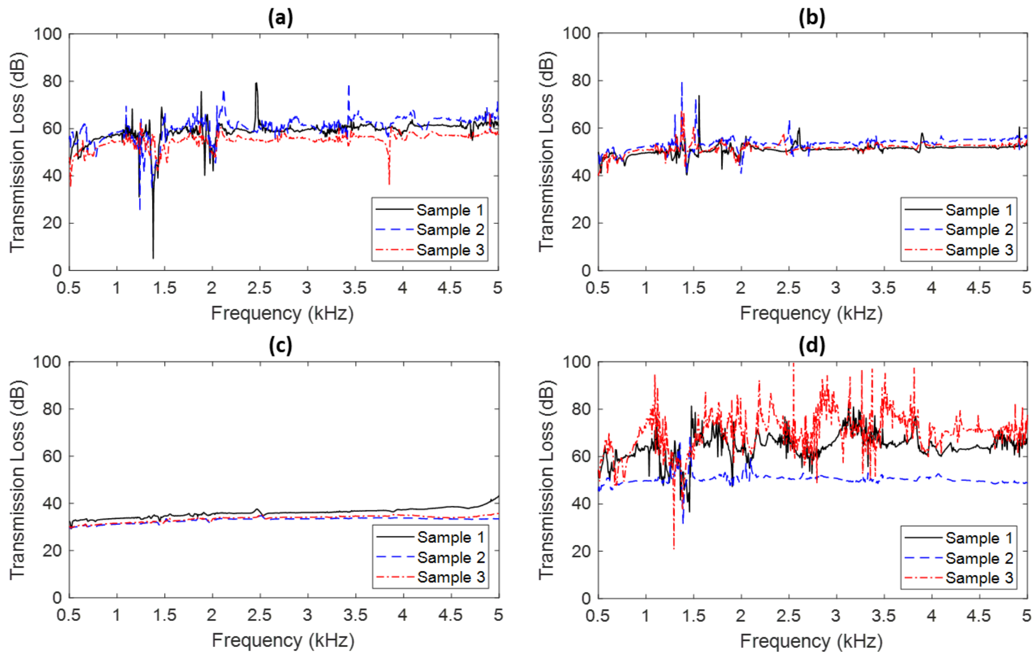

Fig. 2—Transmission loss levels of the three nominally identical samples: (a) without grinding (d=29 mm), (b) grinded by 0.1 mm (d=28.9 mm), (c) grinded by 0.4 mm (d=28.6 mm) and (d) with tape (d=28.6+0.4=29 mm).

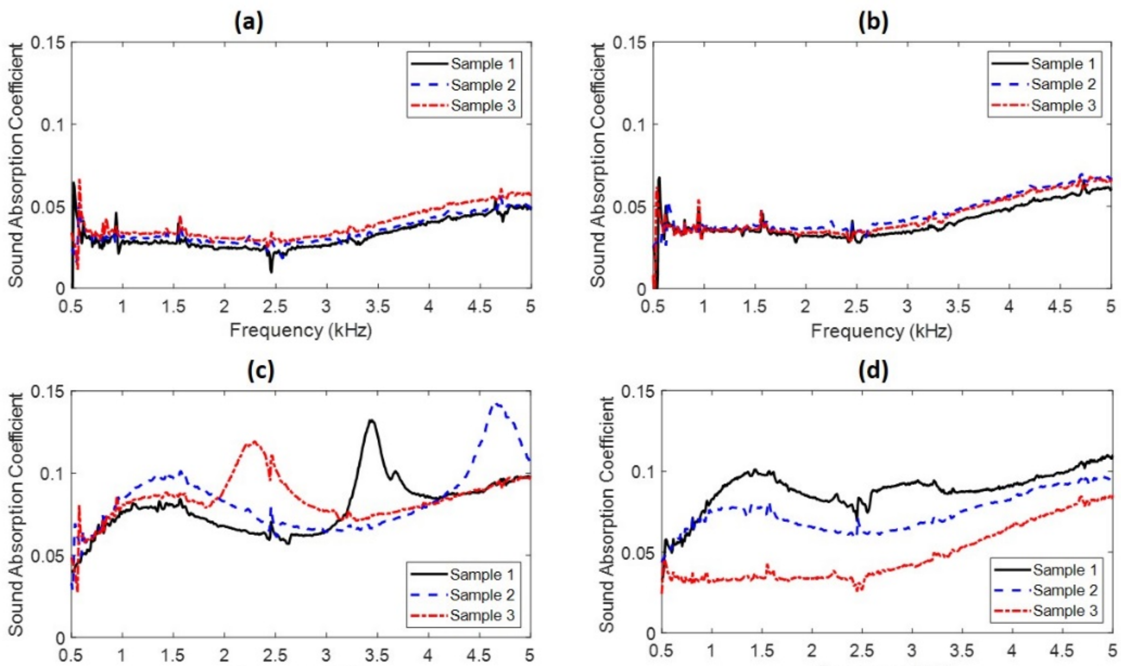

Fig. 3—Sound absorption coefficients of the three nominally identical samples: (a) without grinding (d=29 mm), (b) grinded by 0.1 mm (d=28.9 mm), (c) grinded by 0.4 mm (d=28.6 mm) and (d) with tape (d=28.6+0.4=29 mm).

The averages of the transmission loss levels and sound absorption coefficients of the three nominally identical unmodified samples and the 0.1 mm grinded specimens with petroleum jelly are presented both as FFT and Octave spectrums in Fig. 4. It is obvious that some of the irregularities observed in the FFT spectrums are not seen in the Octave spectrums due to the fact that presenting the results in octave bands has an averaging effect, due to very coarse frequency resolution. Therefore, it may not be possible to clearly identify all the scatters in the measurements arising from the mounting conditions if the FFT spectrums are not used.

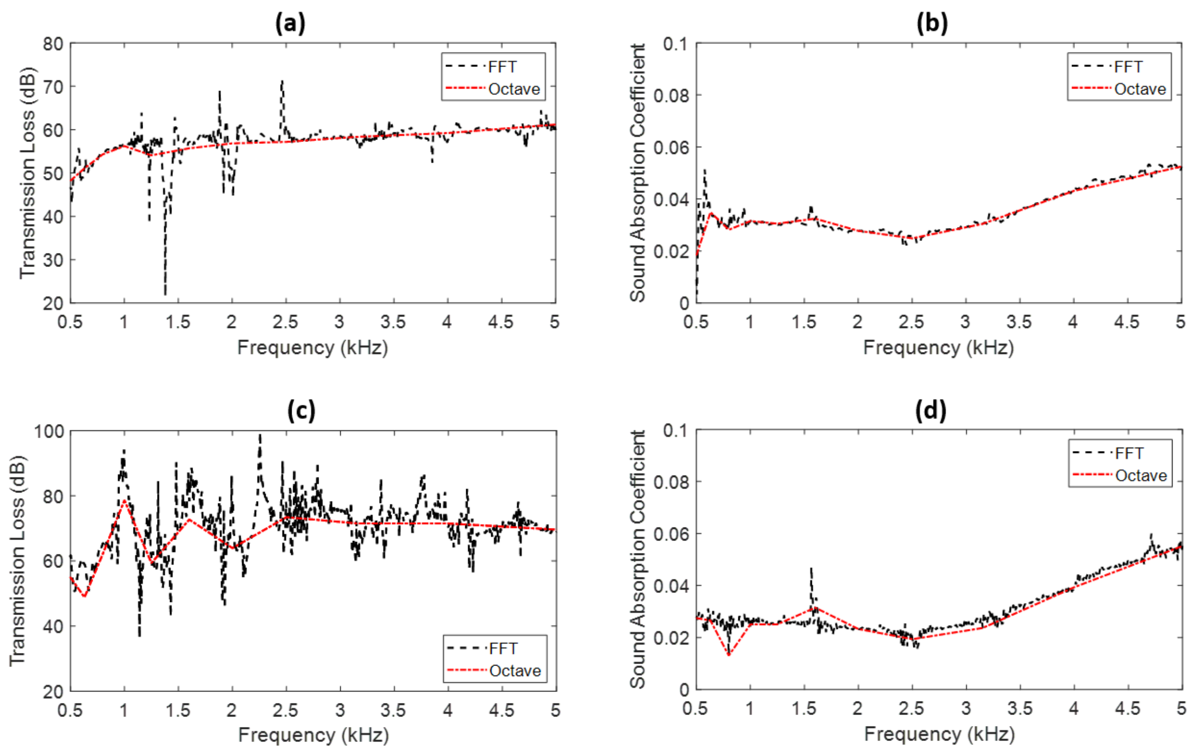

Fig. 4—The averages for the transmission loss levels (right) and sound absorption coefficients (left) of the three nominally identical samples shown as FFT and Octave spectrums: (a-b) unmodified samples (d = 29 mm) and (c-d) 0.1 mm grinded specimens with petroleum jelly (d = 28.9 + 0.1 = 29 mm).

The average values for the transmission loss levels and sound absorption coefficients of the three nominally identical samples for all mounting conditions (i.e., unmodified, grinded by 0.1, 0.2, 0.3, and 0.4 mm and covered with petroleum jelly, tape, wax and cotton) are shown in Fig. 5. The transmission loss levels predicted using the mass law, i.e., Eqn. (4), are also included in Fig. 5. It is seen that the transmission loss levels decrease as the sample diameter is reduced by grinding and the estimated transmission loss levels of the samples covered with tape, wax and cotton are higher than those of the original samples and these modified samples yield more irregular peaks in the spectrum (Fig. 5a). It is clearly seen that the mounting method dramatically affects the identified transmission loss levels. The results in Fig. 5 show that the transmission loss levels of the unmodified samples and the specimens with tape, petroleum jelly, cotton and wax are higher than the ones predicted by the mass law. On the other hand, the transmission loss levels of the samples grinded by more than 0.2 mm are in general less than the ones predicted by the mass law. It is seen that the transmission loss levels of the samples grinded by 0.1 mm become closer to the predicted results when approaching to the critical frequency. If the 0.1 mm grinded sample is examined, it can be seen that the transmission loss gradually increases from 500 to 2000 Hz, then there is a slight drop at 2500 Hz after which the transmission loss gently increases until 5000 Hz. This is a typical behaviour seen in the literature, noting that the transmission loss increases from low frequencies to the critical frequency (mass controlled region), there is drop around the critical frequency and then transmission loss increases again when frequency is increased (damping controlled region)[24, 28]. It should be noted that the natural fiber based composite plates investigated here are different than conventional structures, such as steel plates. For example, the damping of natural fibers based composites are quite high[10], hence the drop in the transmission loss at around the critical frequency is not dramatic. As it is not possible to remove all the air from the samples during manufacturing, some air pockets inevitably remain in these composite samples. In addition, as the methods for manufacturing natural fiber based composites are still not precise today, it is not possible to have a uniform epoxy distribution throughout the composite samples and there can be higher epoxy concentrations in some regions of the samples. All these affect the sound transmission losses of the natural fiber based composites and this can lead to sound transmission loss curves which can be quite different than those for the conventional materials. Further experimental and theoretical investigation of the transmission losses of natural fiber based composites is considered as a topic for a future study. It is also seen that all modifications applied to the original samples such as grinding and covering result in increase in the overall levels of the absorption coefficients (Fig. 5b). As expected, the identified sound absorption coefficients are maximum for the specimen with the highest gap (0.4 mm). The results for the samples with a diameter of 100 mm are shown in Fig. 6. It is seen that the transmission loss levels of the sample grinded by 0.1 mm are close to the predicted results. In general, the 100 mm samples exhibit similar behaviors with the 29 mm samples. It should be noted that small samples (i.e., diameter = 25-35 mm) are widely used in practice as it is only possible to measure sound absorption coefficients and transmission losses for a wide frequency range (i.e., 500-6000 Hz) when small samples are used[13-15, 22-23].

The average transmission loss levels, sound absorption coefficients and their standard deviations in the frequency range of interest (0.5-5.0 kHz) obtained using the FFT and Octave spectrums for all small specimens are listed in Table 1. The results show that the transmission loss measurements are dramatically affected by the mounting conditions while the sound absorption conditions are less sensitive to the mounting conditions. The deviations in the measured transmission loss levels are highest for the samples with tape and wax (10-15 dB). On the other hand, the deviations in the measured sound absorption coefficients are highest for the samples with cotton and tape (1-2%). The deviations both in the transmission loss levels (1-2 dB) and sound absorption coefficients (<0.5%) are lowest for the samples whose diameter reduced by 0.1 and 0.2 mm. It can be said that the samples whose diameters are reduced by only 0.1 mm are quite repeatable and produce reasonable results. For example, the average sound absorption coefficient and transmission loss levels are only 0.5-1.0% higher and 5-7 dB less than those of the original sample, noting that the original samples contain many unexpected peaks/variations. It is recommended that experimentalists in practice should clearly report the details of the mounting conditions for their results and they should check/report not only the Octave spectrums but also the FFT spectrums.

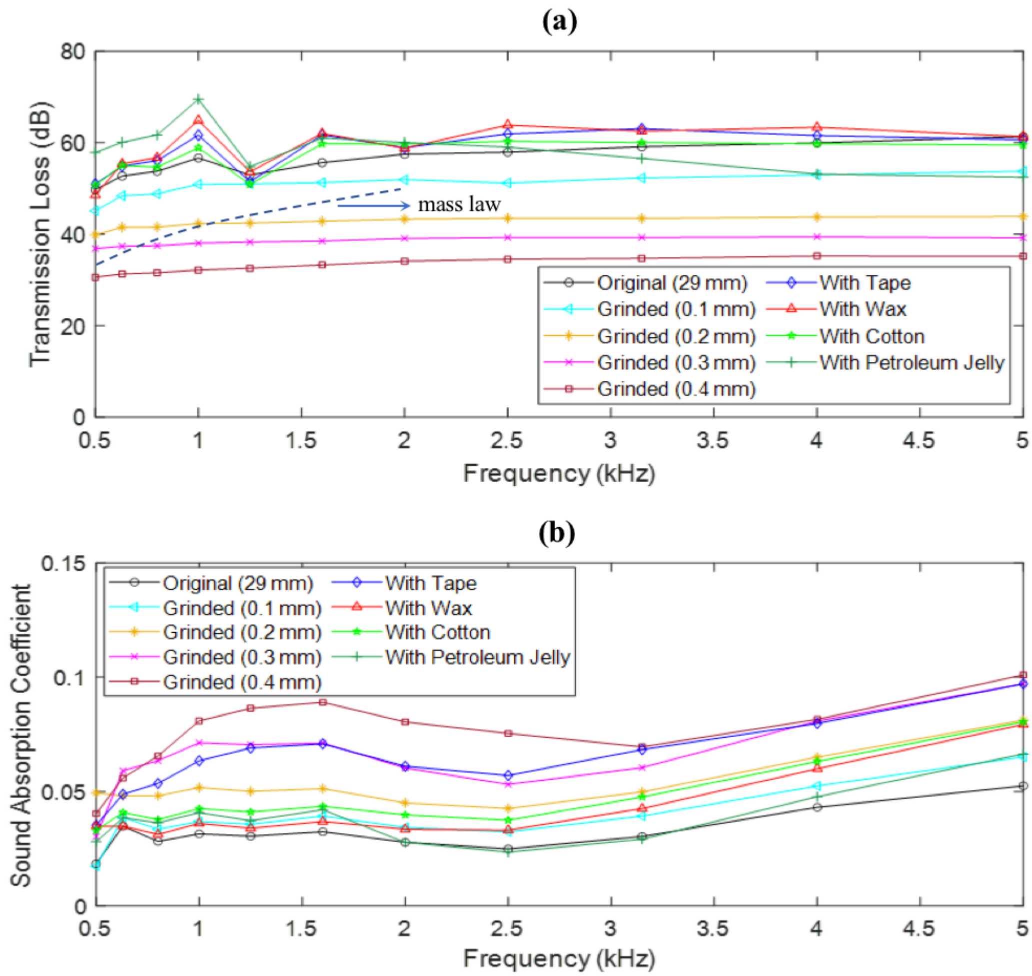

Fig. 5—Average results of the three nominally identical small samples for different mounting conditions: (a) transmission loss levels and (b) sound absorption coefficients.

There are significant differences in the acoustic properties reported for the same biocomposites in the literature[29-31]. It is worth investigating the acoustic properties of all these biocomposites under different mounting conditions in order to quantify the dependency of the identified acoustic properties on mounting conditions. It should be noted that the three problems mentioned in this study are inherent to the hard samples including natural fiber-reinforced composites and they are almost always encountered in practice. The results presented in this paper suggest that, as far as the mounting conditions are concerned, either more guidelines should be provided in the standards or the standards[13-15] should be revised to allow more consistent measurement of the acoustic properties of hard materials using impedance tube method. A recommended guideline for more reliable measurements of the acoustic properties of hard materials is as follows: First, grind the test sample by 0.1 mm and measure its acoustic properties using the impedance tube. Then, grind the sample further by 0.3 mm, apply petroleum jelly around the circumference of the sample and measure the acoustic properties again. Finally, take the average of these two sets of measurements. As the impedance tube method is widely used to identify acoustic performances of materials in practice, it is believed that more experimental and theoretical investigations need to be performed to reduce the uncertainty levels of acoustic properties of materials in impedance tube tests.

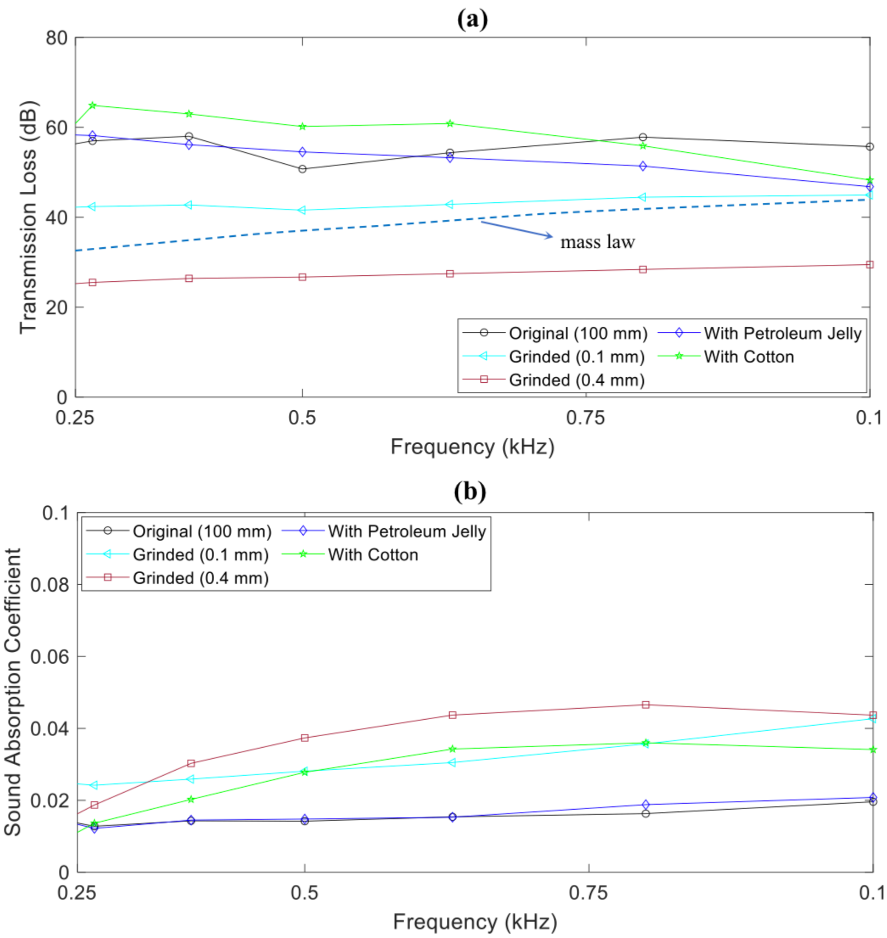

Fig. 6— (a) Transmission loss levels and (b) sound absorption coefficients of large samples for different mounting conditions.

Table 1—Average acoustic properties of the test samples (0.5-5.0 kHz) for different mounting conditions.

Samples	FFT						Octave					
	Transmission Loss (dB)			**Absorption Coefficient (%)**			**Transmission Loss (dB)**			**Absorption Coefficient (%)**		
Original (29 mm)	59.0	±	3.7	3.5	±	0.4	56.1	±	2.9	3.2	±	0.5
Grinded (0.1 mm)	52.4	±	1.8	4.3	±	0.3	50.7	±	1.7	3.9	±	0.4
Grinded (0.2 mm)	43.3	±	1.1	5.5	±	0.3	42.5	±	1.0	5.3	±	0.4
Grinded (0.3 mm)	38.9	±	1.5	7.1	±	0.7	38.4	±	1.5	6.5	±	0.7
Grinded (0.4 mm)	34.0	±	1.7	8.2	±	1.2	33.1	±	1.5	7.5	±	0.8
With Tape	61.5	±	10.8	7.0	±	2.0	58.4	±	8.47	6.4	±	2.1
With Wax	62.2	±	13.9	4.6	±	0.7	59.1	±	11.1	4.1	±	0.7
With Cotton	59.3	±	5.9	5.1	±	1.3	57.2	±	3.7	4.6	±	1.3
With Petroleum Jelly	57.8	±	8.3	4.1	±	0.7	58.7	±	6.2	3.9	±	0.6

4. CONCLUSIONS

The effects of mounting conditions on acoustic properties such as sound absorption coefficients and transmission loss levels of biocomposites in an impedance tube are investigated in this study. It is seen that the sound absorption coefficient and transmission loss measurements are highly affected by the mounting conditions for hard materials (i.e., biocomposites) in the impedance tube method. It is observed that taking measurements using samples whose diameters are very close to the inner diameter of the impedance tube, thus need to be pushed strongly to place them into the tube, produces unrepeatable and unexpected material properties. Therefore, the diameter of the test specimen should be slightly smaller than the inner diameter of the impedance tube. It is found that, if the reduction in the diameter of the sample is significantly more than 0.5%, this will cause huge reductions in the measured sound transmission loss levels and very significant increase in the measured sound absorption coefficients, noting that about 0.3% reduction in diameter produced reasonable and repeatable material properties in this study. As far as the use of sealing materials is concerned, the results obtained in this study suggest that using cotton, tape or wax around the test samples to close the air gaps adversely affects the repeatability of the measurements and produces undesirable peaks in the spectrums. The variations and unexpected results are more clear when the results are presented as FFT spectrums rather than Octave spectrums.

There may be significant differences in the acoustic properties reported for the same biocomposites in the literature. It is highly recommended that experimentalists should obtain suitable and repeatable mounting conditions first and clearly report the details of the mounting conditions for their results obtained using the impedance tube method. One could identify the acoustic properties of hard materials including biocomposite samples with better accuracy by taking into account the outcomes of this paper.

5. ACKNOWLEDGMENTS

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6. REFERENCES

1. C. Alves, P.M.C. Ferrão, A.J.Silva, L.G. Reis, M. Freitas, L.B. Rodrigues and D.E. Alves, "Ecodesign of automotive components making use of natural jute fiber composites", *Journal of Cleaner Production* **18**(4), 313–327, 2009.

2. M.A. Usmani and M. Anas, "Study of natural fibre reinforced composites", *IOP Conference Series: Materials Science and Engineering* **404**(1), 012048, 2018.

3. E.M. Taiwo, K. Yahya and Z. Haron, "Potential of using natural fiber for building acoustic absorber: A review", *Journal of Physics: Conference Series* **1262**, 012017, 2019.

4. N. Karthi, K. Kumaresan, S. Sathish, S. Gokulkumar, L. Prabhu and N. Vigneshkumar, "An overview: Natural fiber reinforced hybrid composites, chemical treatments and application areas", *Materials Today: Proceedings* **27**, 2828-2834, 2020.

5. F. Mahir, K. Keya, B. Sarker, K. Nahiun and R. Khan, "A brief review on natural fiber used as a replacement of synthetic fiber in polymer composites", *Materials Engineering Research* **1**, 86-97, 2019.

6. X. Tang and X. Yan, "Acoustic energy absorption properties of fibrous materials: A review", *Composites Part A: Applied Science and Manufacturing* **101**, 360–380, 2017.

7. P.V. Bansod, T. Mittal and A.R. Mohanty, "Study on the acoustical properties of natural jute material by theoretical and experimental methods for building acoustics applications", *Acoustics Australia* **44**(3), 457–472, 2016.

8. S. Gokulkumar, P.R. Thyla, L. Prabhu and S. Sathish, "Characterization and comparative analysis on mechanical and acoustical properties of camellia sinensis/ananas comosus/class fiber hybrid polymer composites", *Journal of Natural Fibers*, 2019.

9. H. Koruk and G. Genc, "Investigation of the acoustic properties of bio luffa fiber and composite materials", *Materials Letters* **157**, 166–168, 2015.

10. G. Genc and H. Koruk, "Identification of the dynamic characteristics of luffa fiber reinforced bio-composite plates", *Bioresources* **12**, 5358-5368, 2017.

11. G. Genc and H. Koruk, "On the difficulties in manufacturing of luffa fibers reinforced bio-composites and variations in their dynamic properties", in *Proc. InterNoise16*, Institute of Noise Control Engineering, (2016), **5**, 1561-1565.

12. M. Raj, S. Fatima and N. Tandon, "Acoustical properties of denim shoddy based recycled material", in *Proc. InterNoise19*, Institute of Noise Control Engineering, (2019), **6**, 3528-3533.

13. "Standard test method for impedance and absorption of acoustical materials using a tube, two microphones and a digital frequency analysis system", ASTM International Standard ASTM E1050-19, (2019).

14. "Standard test method for normal incidence determination of porous material acoustical properties based on the transfer matrix method", ASTM International Standard ASTM E2611-17, (2017).

15. "Acoustics-determination of sound absorption coefficient and impedance in impedance tube- Part 2: Transfer function method", International Standard ISO 10534–2: (2001).

16. N. Kino and T. Ueno, "Investigation of sample size effects in impedance tube measurements", *Applied Acoustics* **68**(11–12), 1485–1493, 2007.

17. B.H. Song, J.S. Bolton and K.J. Kang, "Effect of circumferential edge constraint on the acoustical properties of glass fiber materials", *The Journal of the Acoustical Society of America* **110**(6), 2902–2916, 2011.

18. A. Cummings, "Impedance tube measurements on porous media: The effects of air-gaps around the sample", *Journal of Sound and Vibration* **151**(1), 63–75, 1991.

19. R. Boonen, P. Sas, W. Desmet, W. Lauriks and G. Vermeir, "Calibration of the two microphone transfer function method with hard wall impedance measurements at different reference sections", *Mechanical Systems and Signal Processing* **23**(5), 1662–1671, 2009.

20. D.R. Stanley, "Impedance tube specimen preparation and mounting issues", in *Proc. InterNoise12*, Institute of Noise Control Engineering, (2012), **7**, 9126-9132.

21. A.F. Seybert, X. Hua and D.W. Herrin, "Controlling uncertainty of sound absorption measurements using the impedance tube method", in *Proc. InterNoise13*, Institute of Noise Control Engineering, (2013), **8**, 869-876.

22. H. Koruk, "An assessment of the performance of impedance tube method", *Noise Control Engineering Journal* **62**(4), 264–274, 2014.

23. S.S. Jung, Y.T. Kim, Y.B. Lee, S.I. Cho and L.K. Lee, "Measurement of sound transmission loss by using impedance tubes", Journal of the Korean Physical Society **53**(2), 596-600, 2008.

24. H. Koruk, "Assessment of the measurement and prediction methods for the acoustic properties of natural fiber samples and evaluation of their properties", *Journal of Natural Fibers*, 2021. Doi: 10.1080/15440478.2021.1907835.

25. E.P. Calius, X. Bremaud, B. Smith and A. Hall, "Negative mass sound shielding structures: Early results", *Physica Status Solidi B* **246**(9), 2089-2097, 2009.

26. T. Fu, Z. Chen, H. Yu, Z. Wang and X. Liu, "An analytical study of sound transmission through corrugated core FGM sandwich plates filled with porous material", *Composites Part B* **151**, 161-172, 2018.

27. M. Liu, L. Peng, Z. Fan and D. Wang, "Sound insulation and mechanical properties of wood damping composites", *Wood Research* **64**(4), 743-758, 2019.

28. B.J. Smith, R.J. Peters, S. Owen, Acoustics and Noise Control, 2nd ed., Pearson Education, London, England, (1996)

29. F. Asdrubali, S. Schiavoni and K.V. Horoshenkov, "A review of sustainable materials for acoustic applications", *Building Acoustics* **19**(4), 283–311, 2012.

30. N.H. Bhingare S. Prakash and V.S. Jatti, "A review on natural and waste material composite as acoustic material", *Polymer Testing* **80**, 106142, 2019.

31. U. Berardi and G. Iannace, "Acoustic characterization of natural fibers for sound absorption applications", Building and Environment **94,** 840–852, 2015.