An impedance tube measurement technique for controlling elastic behavior of test samples

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ABSTRACT

For this paper, a modified sample mounting technique in which a sample is loosely-supported in an impedance tube testing was studied. This alternate mounting technique was compared to the traditional method of holding the test samples inside of the tube. This loosely-supported technique is defined by having a sample intentionally loosely fixed to the inner wall of impedance tube to control elastic behaviour of the test sample itself. In general the influence of the elastic behaviours, due to the shearing resonance, results in unwanted flexural vibrations of the test sample in the tube. This adversely affects the calculated results from the tube measurements. The significance of the impact will depend on the physical properties and/or supporting condition of the test samples. In addition, this influence will decrease the accuracy of not only measured acoustic properties but also the predicted acoustic parameter (e.g. Biot's parameters such as porosity and tortuosity) estimated from the absorption coefficients curve versus frequency using an inverse characterization method. Another candidate for controlling the flexural vibration is the well-known nailing technique, which directly prevents the vibration of test sample. However, nailing may change or damage the internal structure of the sample materials. In this report, advantages of the loosely-supported technique is presented. This technique does not change the internal structure of a sample and is minimally influenced by the cutting accuracy of the test samples. Validation of this method will be shown using multiple glass wool and recycled fiber samples with varying bulk densities.

Keywords: Impedance tube, absorption coefficients, glass wool: 72.7

1. INTRODUCTION

When testing acoustical materials for sound absorption using an impedance tube, the results may be adversely affected by a shearing vibration resonance [1] of the test sample due to fit within the tube. This effect is influenced by the cutting accuracy (radius and circularity) of the materials. This effect may reduce accuracy of the measured acoustic property (normal incidence sound absorption coefficients, specific impedances and related results) and impact the inverse characterization estimation of the acoustic Biot's parameters. This resonance vibration behavior has been measured using a laser velocimeter and predicted via FEA modeling by Song and Bolton [2]. According to the ASTM E1050 Standard [3] "the sample must fit snugly into the specimen holder, not so tightly that is bulges in the center, nor so loosely that there is space between its edge and the holder", which indicates the importance of the sample preparation and fit. The current approach to reduce the elastic behavior has generally been focused on ways of cutting and supporting test sample in tube.

First, three different diameter push cutters were tested on fiber material [4]. Based on experimental results, determining the proper diameter of a push cutter is dependent on both material type and thickness along with other material property.

Second, an alternate method of supporting the test sample to control or reduce the elastic behavior (such as resonant vibration) of the sample in the tube were also tested using fibrous material [5]. The experimental method used for the evaluation was to constrain the sample using paper-honeycomb attached to the surface of the sample. The measured results of this approach determined this was not an effective method to improve the accuracy of the absorption coefficient curve. The results also indicated that the dominant resonance is not along the surface of the test sample.

Thirdly, the shearing resonance motion of the test sample along length of the tube was also confirmed by FE modeling at specific frequencies [2; 6]. These results reinforce the need for a new approach of supporting the sample beyond what has already been tested using the above approaches. Additionally most of the approaches presented by others have been related to measurements of the sound transmission loss in the tube [7].

Other techniques that are commonly used to control the elastic behavior may damage or change the internal structure of the materials. Therefore the loosely-supported technique, which neither changes the internal structure of a sample nor depends on the cutting accuracy of a sample, has many practical advantages. This method will be experimentally evaluated using glass wool and recycled fiber samples with different bulk densities.

2. LOOSELY–SUPPORTED TECHNIQUE

In past studies, a loosely-supported technique has been used for reducing elastic behavior in the impedance tube [8]. The inner diameter of the sample holder section of the impedance tube was increased by 4 to 6 mm compared to the inner diameter of the source section of the tube. This allows the sample to be to loosely supported with minimum constraint from the inside wall of sample holder, as shown Figure 1. Unfortunately this setup is not flexible for testing with variable air gap behind the sample. It is limited for only specifically prepared back air-gap conditions.

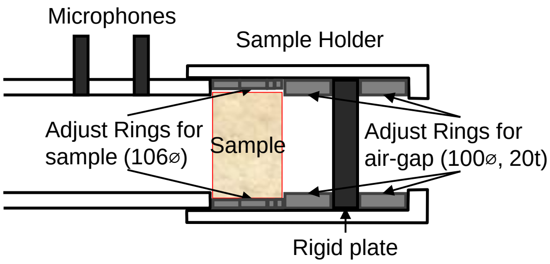


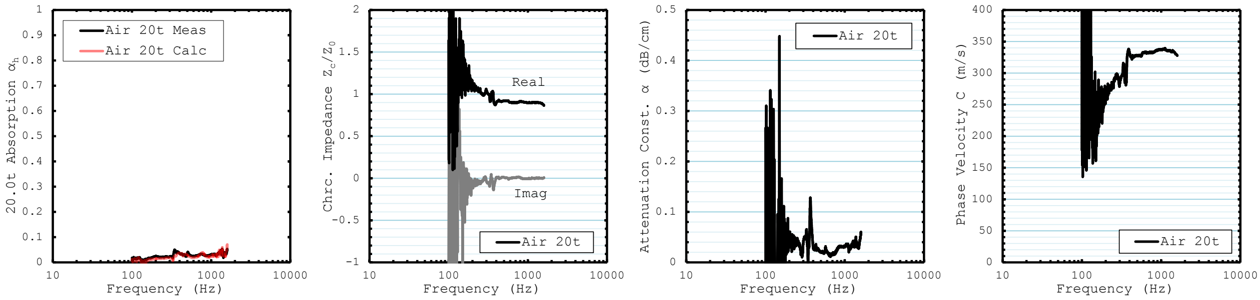
Figure 1 – Example illustration for the large tube of B&K Type 4206 with a specific loosely-supported holder

Additionally, in section 6, another type of loosely-supported technique is discussed. This setup is based on a commercially available impedance tube and it has the capability of adapting to variable back air-gap length.

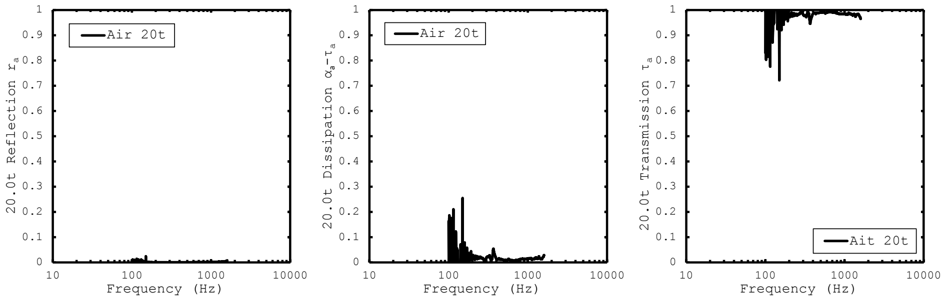
3. Acoustic performance of Loosely–Supported holder

In order to confirm the acoustic performance of the specific loosely-supported holder itself, an equivalent 20 mm thick air cavity was measured. The acoustic performance (sound absorption coefficient, specific impedance ratio and propagation constant) were calculated using the two-cavity method [9]. The Energy parameters (reflection, dissipation and transmittance) for the equivalent 20 mm air cavity with an air termination, were calculated by methods described in reference [10], and are shown in Figure 2.

From these results, the flat portion of the real part of the characteristic impedance is calculated as 0.90 above 400 Hz. This number is almost as same as a ratio of the cross section between the original sample holder tube and the specific loosely-supported holder. The additional material parameters were calculated to be; attenuation constant of 0.003 dB/cm; phase velocity of 330 to 340 m/s; energy reflectance around zero; energy dissipation around zero and energy transmission around one. These numbers are reasonable as properties for air.



(a) sound absorption coefficients (b) Characteristic impedances (c) Attenuation constants (d) Phase velocities



(e) Energy reflectance (f) Energy dissipation (g) Energy transmittance

Figure 2 – Results of the 20 mm air cavity for specific loosely-supported holder impedance tube

4. RESULT OF PHYSICAL PROPERTIES OF TARGET TEST SAMPLE

For validating the performance of the loosely-supported technique, three different nominal bulk density (GW30K, GW60k and GW90K) glass wool samples were cut using the push cutter shown in Figure 3 (104.5⌀). For each density of material seven pieces of glass wool were tested. The physical property of the test sample are shown via average and standard deviation (SD) for the diameter, thickness and bulk density, in Table 1.

Table 1 — Physical properties of test samples

	Diameter ⌀ [mm]		Thickness *t* [mm]		Bulk Density *r* [kg/m^3]	
	avg	SD	avg	SD	avg	SD
GW30K	105.79	0.62	19.07	0.36	31.0	3.0
GW60K	105.09	0.17	19.59	0.17	58.8	3.3
GW90K	104.96	0.22	19.82	0.15	90.3	5.8

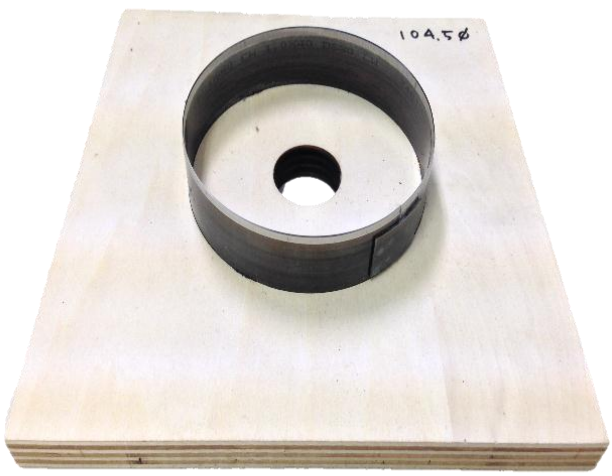
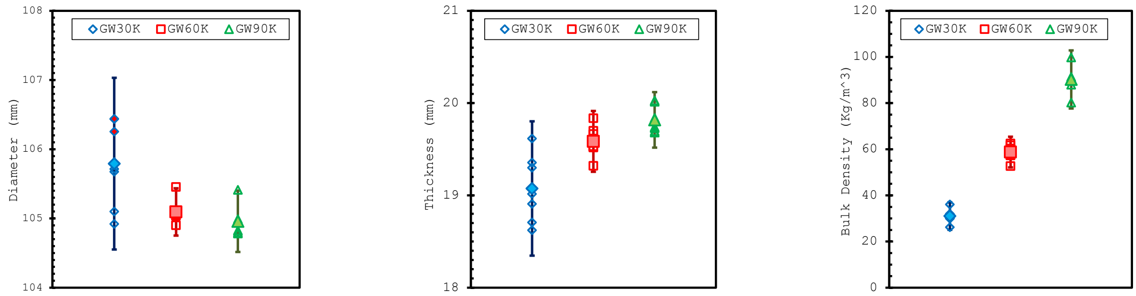


Figure 3 – Push Cutter for loosely-supported holder (104.5⌀)

There is a trend for this type of fiber material, as the samples with the larger nominal bulk density have lower diameter variability. The sample with the lowest density, GW30K, had a standard deviation (SD) of three times for the diameter and two times for the thickness when compared to both of the higher density samples, GW60K and GW90K (as shown in Figure – 4 (a) and (b)). Since this sample has the lowest bulk density, it may be more easily deformed during the cutting process when using the push cutter as compared to the higher bulk density samples. And this sample (GW30K) also has the highest percentage variability for the bulk density when compared to the other sample. This means the GW30K has the large potential uncertainty in the results.



(a) Diameters (b) Thicknesses (c) Bulk Densities

Figure 4 – Distribution of glass wool sample's physical properties (with average and $\pm 2\sigma$)

5. RESULT OF ACOUSTIC PERFORMANCE OF LOOSELY-SUPPORT

Results of the acoustic performance for the different bulk density glass wool samples (GW30K, GW60K and GW 90K) are shown in Figures – 5, 6 and 7, respectively. Two of the low density samples, GW30K, were larger than the inner diameter of this specific loosely-supported holder (106⌀) as shown in Figure – 4 (a).

The measurement results for these larger samples are presented in section 5.1 and are considered a partly loose-support condition. In section 5.2 the results for the loose-support condition for all of the remaining test samples that have a diameter less than inner diameter of sample holder are presented.

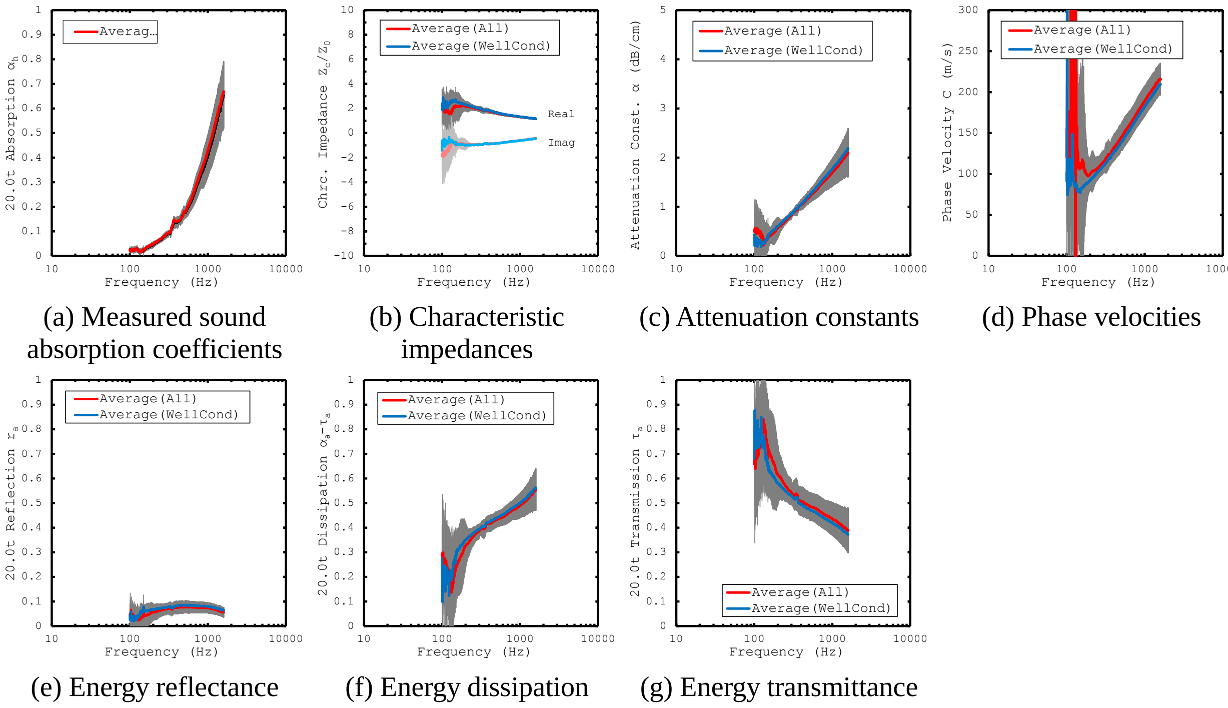
5.1 Case of Partly Loosely-Support Condition (GW30K)

As previously mentioned, due to larger diameter of GW30K sample, the results for this material demonstrates the typical elastic behavior due to undesirable flexural vibrations of the test sample mounted in the tube. The results are presented as the average the seven samples (red), average of well-conditioned (proper diameter) samples (blue) and estimated coverage $\pm 2\sigma$ (gray area) in Figure – 5. This shearing resonance is most pronounced around 150 Hz in the (b) Characteristic impedance, (c) Attenuation constant, (d) Phase velocity, (f) Energy dissipation and (g) Energy transmittance in Figure – 5.

5.2 Case of Loosely-Support Condition (GW60K and GW90K)

On the other hand, all of the cut sample's diameters for both the GW60K and the GW90K in Figure 4 – (b) and (c) respectively, were smaller than the inner diameter of the loosely-support holder (106⌀) when compared to Figure 4 – (a). This indicates that these sample should demonstrate less effect of the shearing resonance and thus can be measured in the loosely-support condition. The results of the GW60K and GW90K samples are shown in Figures – 6 and 7 respectively, in which the results of the average of the seven sample (red) and estimated coverage $\pm 2\sigma$ (gray area) are presented.

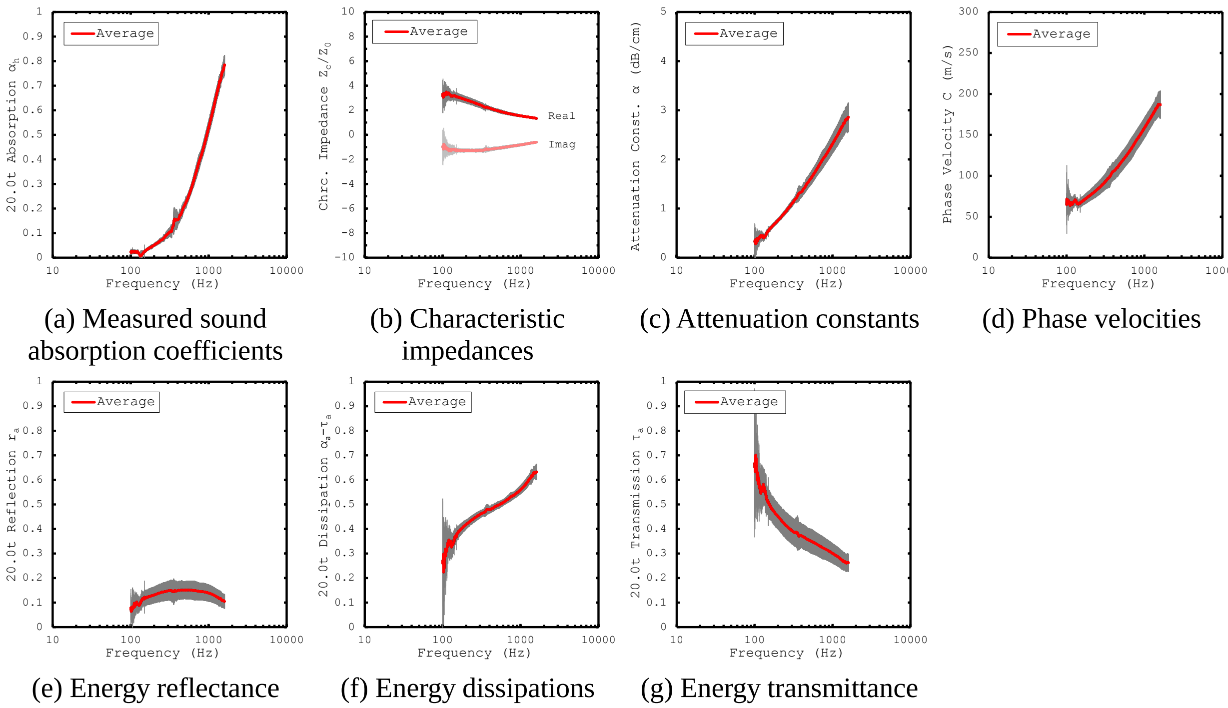
When compared with the case of partly loosely-support condition in section 5.1, both the result of the GW60K and GW90K samples demonstrate minimal elastic behavior (unnecessary flexural vibrations) on the test sample in the tube. This illustrates the importance of the diameter of the test sample and dictates whether the sample meets the criteria to be measured using the loosely-support condition [11].



(a) Measured sound absorption coefficients (b) Characteristic impedances (c) Attenuation constants (d) Phase velocities

(e) Energy reflectance (f) Energy dissipation (g) Energy transmittance

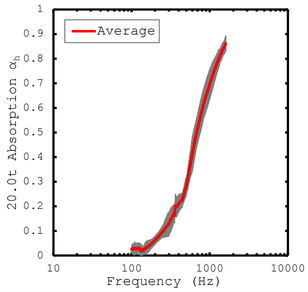
Figure 5 –Measurement results for the GW30K using the loosely-supported sample holder (red line: average of all samples, gray region: $\pm 2\sigma$ region from red line, and blue line: average of unsupported samples as well condition)



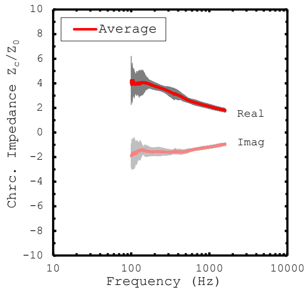
(a) Measured sound absorption coefficients (b) Characteristic impedances (c) Attenuation constants (d) Phase velocities

(e) Energy reflectance (f) Energy dissipations (g) Energy transmittance

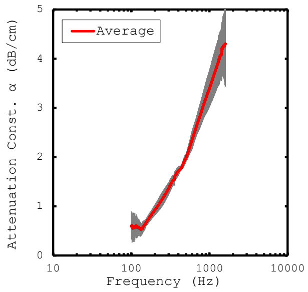
Figure – 6 Measurement results for the GW60K using the Loosely-supported sample holder (red line: average of all samples, gray region: $\pm 2\sigma$ region from red line)



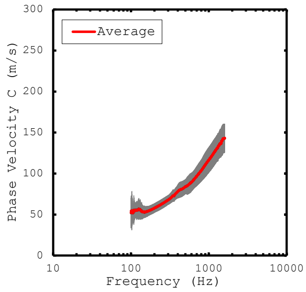
(a) Measured sound absorption coefficients



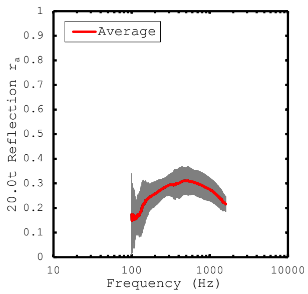
(b) Characteristic impedances



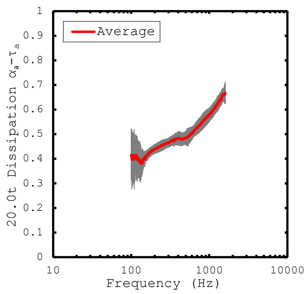
(c) Attenuation constants



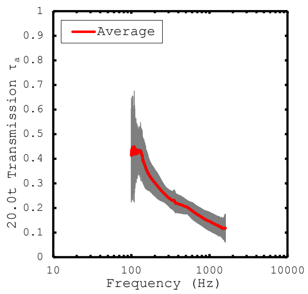
(d) Phase velocities



(e) Energy reflectance



(f) Energy dissipation



(g) Energy transmittance

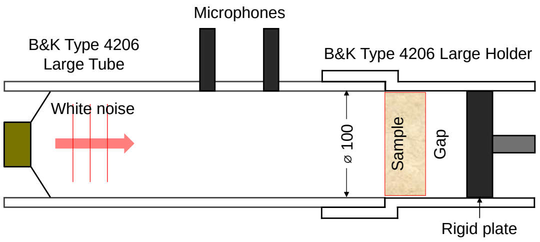
Figure – 7 Measurement results for the GW90K using the loosely-supported sample holder

(red line: average of all samples, gray region: ±2σ region from red line)

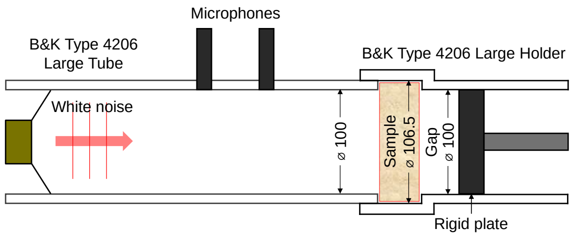
6. ANOTHER TYPE OF LOOSELY-SUPPORTED TECHNIQUE

6.1 B&K Loosely-Support Sample Holder Setup

The previous discussion of the effectiveness of the loosely-supported technique was presented using a custom designed loosely-supported holder. In order to validate the performance of loosely-supported technique itself, another type of loosely-supported setup, as shown in Figure – 8, was evaluated [12]. The setup (b) is not a newly developed sample holder, but is rather an alternate tube configuration for the standard Brüel and Kjær Type 4206 large impedance tube. Through the remainder of the paper this configuration will be called the “B&K loosely-support setup”. For this configuration all of the hardware utilized is the same as what is delivered with the standard product from Brüel and Kjær.



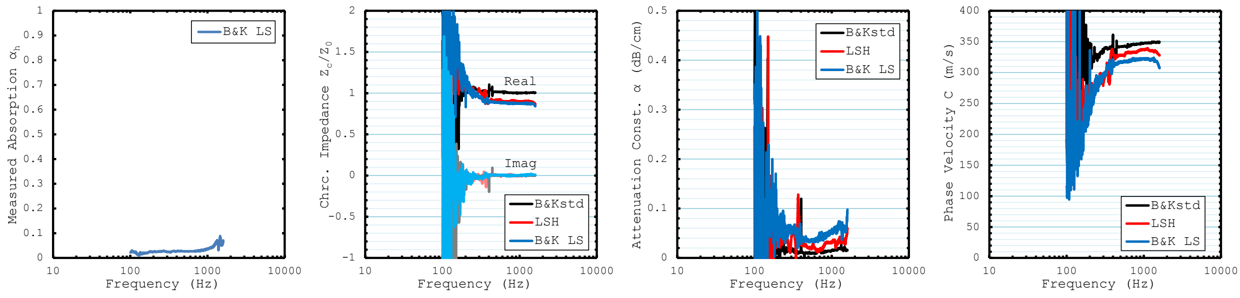
(a) Standard Setup



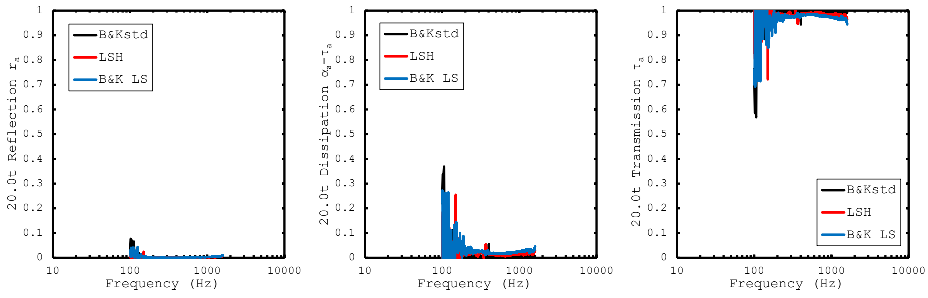
(b) Loosely-supported Setup

Figure – 8 Brüel and Kjær Type 4206 Large Impedance Tube with loosely-supported condition

Because one major draw-backs for utilizing a loosely-supported sample holder, as shown in Figure – 1, is the setup is too time-consuming to configure the apparatus with the desired back air-gap, for normal daily testing. To overcome this limitation, another type of loose-supported technique was evaluated. The standard and modified setup, using a production impedance tube, is shown in Figure – 8 (a) and (b). At present, its only limitation is the thickness of the actual test sample itself, with a maximum of 30 mm length based on the physical geometry of the design.



(a) Measured sound absorption coefficients (b) Characteristic impedance (c) Attenuation constants (d) Phase velocities



(e) Energy reflectance (f) Energy dissipation (g) Energy transmittance

Figure 9 – Validation test results of B&K loosely-supported setup (14 mm thickness air) compared with B&K standard setup and specific loosely-supported holder tube (20 mm thickness air)

6.2 Acoustic Performance of B&K Loosely-Supported Setup

First, a validation test was done for an air cavity of the equivalent thickness as was tested in section 2. The comparison is shown in Figure – 9 for a 14 mm and 20 mm thick air cavity, in which B&K std (in black) are the results of standard Brüel and Kjær Type 4206 Large tube sample holder. For comparing with the results presented in section 3, the result of the LSH (in red) "Loosely-Supported Holder" from Figure – 2 and the B&K LS (in blue) are the results of the B&K Loosely-Supported setup are also shown in Figure 9. Based on these results it can be shown that the B&K Loosely-Supported setup produces results, within normal measurement variability, as the LSH. This indicates that the two designs produce equivalent results.

Additionally, the real part of characteristic impedance in the B&K LS is 0.88, which is approximately the same as LSH, shown in Figure 9 – (b). This result again is approximately equal to the ratio of the cross section between the standard tube and the sample holder section. It means that this bias error can be compensated for, based on theory, for generating a more accurate calculation of the materials acoustical properties.

6.3 Test Sample for B&K Loosely-Supported Setup

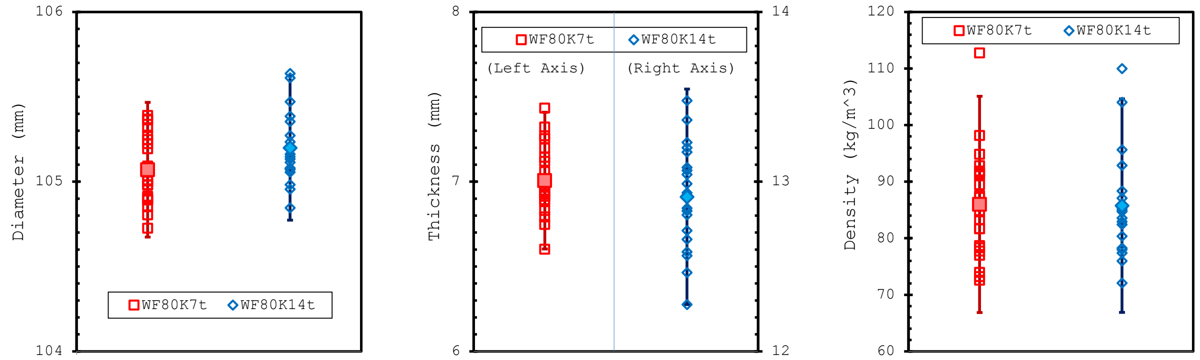
Due to the sample size limitation of existing B&K loosely-supported setup, a 7 mm and a 14 mm thick sample of recycled fiber material (WF80K14t and WF80K7t) were evaluated. These samples consist of several kind of recycled fibers. The physical properties for these samples are shown in Table – 2 and the recycled fiber sample's physical properties (diameters, thicknesses and bulk densities) are graphed in Figure – 10.

Table – 2 Averaged physical properties of recycled fiber test samples

	Diameter ⌀ [mm]		Thickness t [mm]		Bulk Density ρ [kg/m^3]	
	average	SD	average	SD	average	SD
WF80K14t	105.20	0.21	12.91	0.32	85.77	9.44
WF80K7t	105.07	0.20	7.01	0.20	85.98	9.57

While the bulk density for the recycled fiber is more widely-varied than the above measured glass wool samples, the diameters of both the WF80K7t and WF80K14t are less than the 106.5 mm inner tube diameter, allowing them to be tested using the B&K loosely-supported setup.

Based the physical properties of the recycled fiber material, most notably the diameter, we can expect to control the elastic behavior when utilizing the B&K loosely-supported setup.

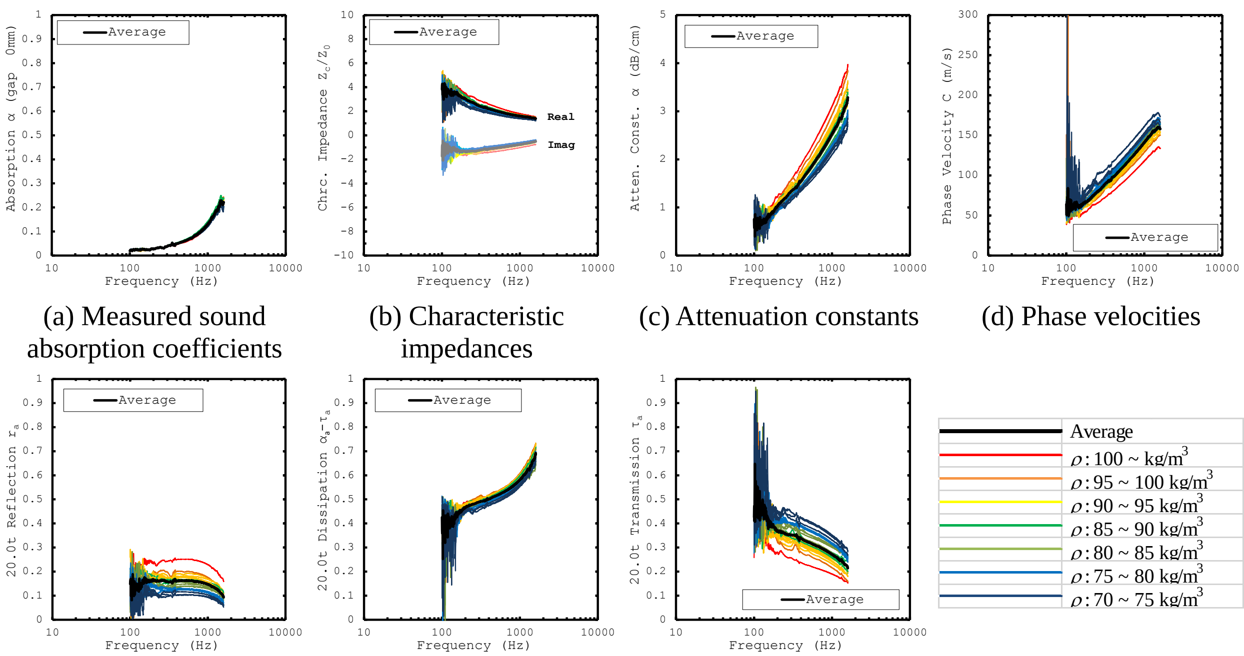


(a) Diameters (b) Thicknesses (c) Bulk Densities

Figure – 10 Distribution of recycled fiber sample's physical properties (with average ± 2σ)

6.4 Result of Acoustic Performance of B&K loosely-supported setup

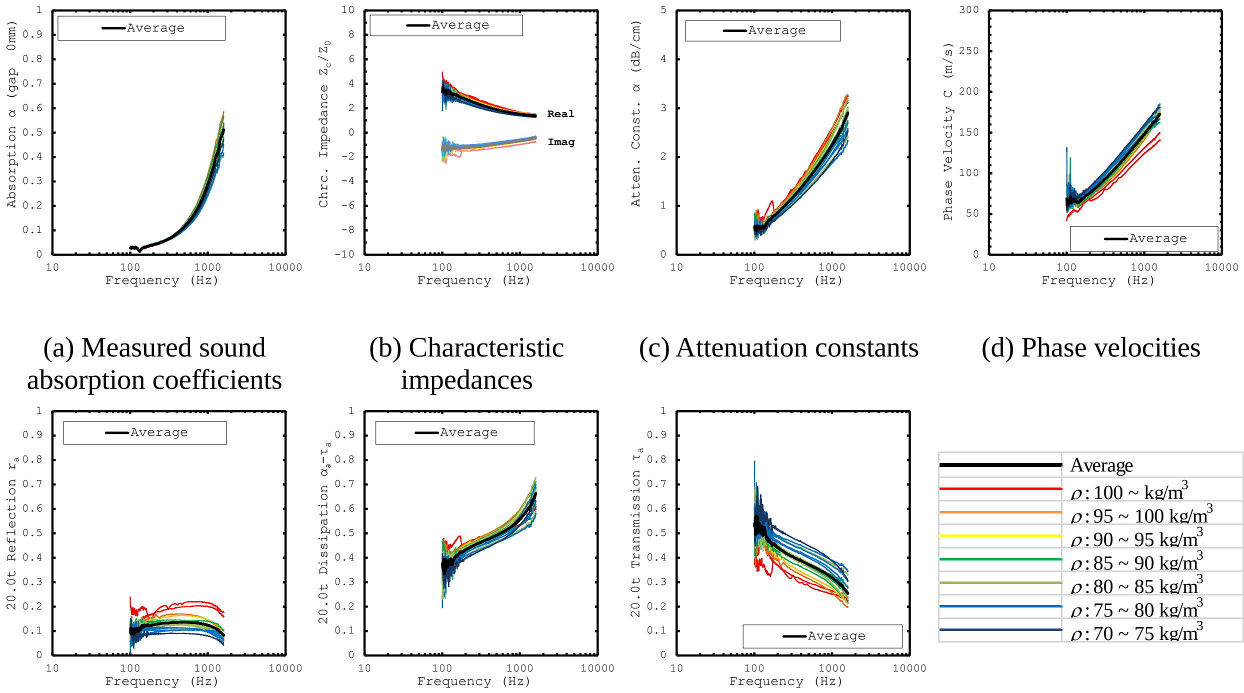
Figures – 11 and 12, display the results of the acoustic performance of the 7 mm and 14 mm thick recycled fiber material (WF80K7t and WF80K14t) when tested with the B&K loosely-support setup. The trends displayed in these figures are similar to what was shown in Figures – 5 to 7. These displays however include additional colored curve showing the results for the variation in the bulk densities of each samples. Based on these measurements the B&K loosely-support setup condition is able to control the elastic behavior (unnecessary flexural vibrations) of the test samples in the tube quite effectively.



(a) Measured sound absorption coefficients (b) Characteristic impedances (c) Attenuation constants (d) Phase velocities

(e) Energy reflectance (f) Energy dissipations (g) Energy transmittance

Figure – 11 Acoustic properties of WF80K7t recycled fiber sample



(a) Measured sound absorption coefficients (b) Characteristic impedances (c) Attenuation constants (d) Phase velocities

(e) Energy reflectance (f) Energy dissipations (g) Energy transmittance

Figure – 12 Acoustic properties of WF80K14t recycled fiber sample

7. DISCUSSIONS

Some of the common tendencies demonstrated for the sound absorption testing in an impedance tube are shown in Figure – 5 (a), Figure – 6 (a), Figure – 7 (a), Figure – 11 (a) and Figure – 12 (a). All of the graphs of the measured sound absorption coefficients for these samples demonstrate a broad variation in higher frequency range (absorption coefficients higher than 0.2) for each sample. This can be attributed to the wide range of physical properties within each sample group. Since these were non-faced materials the measured sound absorption coefficients is proportional to frequency.

On the other hands, in the lower frequency range of the measured sound absorption coefficients, the results of the samples are controlled by the bulk densities. While some variation of the results in this frequency range is inevitable, as noted in Repeatability and Reproducibility table in the ASTM E1050 standard [3], there is risk that this variation may hide some elastic behavior (unnecessary flexural vibrations) of the test sample itself.

Additionally some of the results are displayed using complex data (real and imaginary) as the energy ratio. It can be considered a complementary method of presenting the results for the sound absorption coefficients and the other results (such as characteristic impedances, attenuation constants, phase velocities, energy reflectance, energy dissipations and energy transmittance) and can be helpful for gaining a deeper understanding of test material.

8. CONCLUSION

In this report, a loosely-supported technique for controlling the elastic behavior (unnecessary flexural vibrations) of the test samples in the impedance tube was demonstrated for two fiber materials (glass wool and recycled fiber material) with widely-varied physical property.

Based on the analysis results, there are a few general conclusions:

- First to minimize the impact of the shearing resonance, keeping the diameter of the test sample smaller than the inner diameter of loosely-supported sample holder will provide very stable results without the characteristics of any elastic behavior.
- Second, an expanded inner sample holder tube diameter (+ 6.5 %), when using the loosely-support setup, is able to cover a certain deviation in diameter of the test samples. This increase in diameter should not require any special greasing treatment around the test sample to protect

against air leakage.

- Third, each physical property of the sample material is an important parameter to consider when comparing the measured sound absorption coefficients curves for samples with low, middle or high absorption coefficients, because the measured results are sensitive to the variation in the physical property. With the order of importance based on the fiber samples tested, sample diameter then bulk density being the two most influential.

Additional work is needed to develop a more practical procedure for utilizing the loosely-supported setup. This includes development of a procedure to compensate for different diameters of material both during the measurement and in preparation along with a more flexible tube option for covering longer thickness samples with varying depth air cavities.

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