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Comparative Study of the ASTM E1050 Standard for Different Impedance Tube Lengths

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The two microphone acoustic impedance tube is used to measure the acoustic impedance and absorption coefficient properties for absorptive materials. A commonly followed test method for this is described by the standard ASTM E1050. This test standard is popular compared to alternative test methods due to its repeatability, speed of test and small sample size requirements. The two microphone broadband noise source based test method was introduced in 1985 and was an update to the single microphone sinusoidal excitation method given by ASTM C384. The ASTM E1050 standard was updated in 1998 to include changes in the required physical dimensions of the tube. Specifically, the tube length was said to be increased to be sufficiently long to meet the requirement that plane waves be fully developed before reaching the microphones and test specimen. Further, a minimum of three tube diameters was specified between the sound source and the nearest microphone to allow for sufficient distance for the subsiding of any non-plane waves propagating within the tube. Using two different tube lengths meeting the requirements of the two versions of the standard, this study investigated experimentally whether any differences resulted in the measured normal incidence absorption for multiple test samples as a result of the prescribed dimensional changes. The precision of the measured results are compared using the repeatability and reproducibility requirements defined in Table 2 of the E1050 standard.

1 INTRODUCTION

Knowing the acoustical properties of materials used for products and engineering applications is important for the understanding and management of noise in engineering projects and design of products. Examples of important acoustic material properties which aid in the

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design and control of noise are absorption coefficient, reflection factor, and surfaces impedance. These material proprieties however are often not readily available for every material and they may vary significantly depending on the materials consistency, density and general shape [1].

One of the most important and often used acoustic properties of a material is absorption coefficient which is a measurement of the sound energy that a material can absorb from an incident sound wave. Sound absorption is often measured using reverberation room tests such as that specified by the ASTM C423-09a standard [2]. These tests are relatively complicated requiring costly facilities, large sample sizes and specialized equipment. The results from this approach can also vary depending on the overall shape, size of the sample and the selected mounting condition. This method is also an indirect method of calculating the random incidence sound absorption based on measured revelation time. The assumption is that the change is due to the presence of the sample in the room. To overcome these drawbacks the use of the acoustic impedance tube is often used to measure and compare the relative values of sound absorption when it is impractical to perform random incident measurements in a reverberation room. For this, one of the most popular techniques used today to describe the basic acoustic performance of absorptive materials is the ASTM E1050 - Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and a Digital Frequency Analysis System. This measurement technique was introduced in 1985 and is a popular used approach given its advantages including speed of the test, good repeatability as well as the small sample size requirement. In this method directly measure the reflection coefficient, hence the absorption coefficient is easily calculated as described in equation 23 of the E1050 standard.

There is another test method, ASTM E2611 [3], available using a modified impedance tube with 4 microphones locations. One of the outputs of this method is the normal incidence absorption coefficient with a hard backing, equation 28. This calculation should output results equivalent to the E1050 method. A recent study found comparing resulting calculations from the Two and Four Microphone Standing Wave Tube [4] demonstrated that for limp fibrous materials correlation was quite good between the E1050 and E2611. However, as the materials became more difficult to measure/model the correlation did not meet the reproducibility requirement to consider the results acceptable. This makes this method, also being an indirect method of measuring the absorption coefficient, equally as difficult as the C423 method for obtaining reliably acceptable results.

The two microphone broadband noise source based test method detailed by the ASTM E-1050[5,7] standard is an update to the single microphone sinusoidal excitation method, the ASTM C384 [6]. Since the E1050's release in 1985 there have been very few changes to the physical layout of the two microphone apparatus. The acoustic impedance tube is usually a hollow cylinder or rectangular duct with constant dimensions from end to end with a test sample holder at one end against either a ridged backing or with a known air space depending on the intended use. A sound source is located at the other end of the tube. Two or more microphones are located along the length of the tube at locations meeting given specifications. The working frequency range of the apparatus is dictated by the diameter of the tube for the upper frequency limitation and microphone separation distance dictates the lower usable frequency [5].

In 1998, a revision to the standard [7] detailed a change to the physical specification of the tube in which the distance from the source to the first microphone location was increased. Section 6.2.3 of the 1985 standard specified that the length of the tube should be kept as short as possible to maintain the required signal to noise ratio and to minimize the added absorption due to the losses of the tube. Section 6.5.3 further states that the recommended distance from the source to the nearest microphone location be no less than one tube diameter [5]. In the 1998 update of the standard, the section pertaining to the tube length (Section 6.2.4) specifies that, "the tube should be sufficiently long as plane waves are fully developed before reaching the microphones and test specimen. A minimum of three tube diameters must be allowed between sound source and the nearest microphone. The sound source may generate nonplane waves along with desired plane waves. The nonplane waves usually will subside at a distance equivalent to three tube diameters from the source" [7].

The purpose of this study is to experimentally investigate whether the hardware modification recommended in the standard would result in a measureable difference in the final normal incidence absorption results. The tests were carried out for several different test samples. The outcome of the measured absorption coefficients are compared against the expected repeatability and reproducibility as defined in Table 2 of the 1998 version of the E1050 standard.

2 EXPERIMENTAL SETUP

For this study, two impedance tubes which were identical in all aspects except length were used. The first tube was constructed such that the distance between the plane of the source and the centre of the microphone nearest to the source was 150 mm as illustrated in Figure 1a. This design is in compliance to the 1985 version of the ASTM E1050 standard. For the second tube, the distance from the plane of the source to the centre of the microphone nearest to the source was 300 mm which is the minimum recommendation length in accordance to the updated 1998 standard. The updated tube design is illustrated in Figure 1b. All other dimensional aspects of the two tube designs were identical to each other including the critical distance from the microphone locations and the position of the test sample.

The measurement and analysis system was a Bruel and Kjaer PULSE Data Acquisition system consisting of a Type 4206 Impedance Tube kit with two Type 4187 ¼ inch condenser microphones, a Type 3160-A-042 LAN Xi acquisition module and a Type 2716C amplifier. The hardware was connected to a laptop PC running version 15.1.0.15 of the Type 7758 PULSE software designed for material testing. The microphones were calibrated before and after the measurements using a Type 4231 acoustic calibrator and DP-0775 ¼" adaptor.

The Type 4187 microphone design selected for the measurements has a non-removable protection grid that forms an airtight front cavity when inserted into the impedance tube at the depth according to the test standard. This provides a coupling between impedance tube and the microphones that is well defined with respect to phase. The result is an optimized measurement accuracy of the measurement results.

For the study, only the 100 mm diameter impedance tube was selected given that this configuration locates the test sample nearer to the sound source compared to the 29 mm diameter tube intended for analysis at higher frequencies. This 100 mm tube has 3 microphone mounting positions available based on the desired measurement frequency range. For our experiments only microphone positions 2 and 3 were used which have a 50 mm separation distance. Based on calculations for the useable frequency range in the ASTM E 1050 standards, this configuration provides useable data within the frequency range of 100-1600Hz.

3 TEST PROCEDURE

Four different representative test material samples were studied and are identified as samples A through D. Sample A was a 25 mm thick light density open cell reference foam. Sample B was a commercial composite material intended for use in harsh industrial environments and consisted of a 4 mm layer of medium density foam laminated to a heavy weight 3 mm layer of rubber. Sample C was a 15 mm thick medium weight fiber absorption pad used for automotive applications. Sample D was a 17 mm thick medium weight fiber absorption pad with a protective backing layer, also intended for automotive applications. Photos of each sample is pictured in Figure 2.

The procedure specified by the ASTM E1050 versions was strictly followed during all the tests. The room temperature, barometric pressure and relative humidity was recorded and applied to the calculation of the speed of sound and density of air. The microphones were calibrated as was the system to account for any phase or amplitude mismatch in the calculation of the frequency response function from the cross spectrum of the two microphones. The analyzer properties were set to a 2Hz resolution and with a 25.3 second measurement for a BT product meeting the minimum requirement according to section 9.2 of the standard. This was done to minimum random errors in the measurement.

For each material, the test was repeated three times using the short impedance tube (1985 standard) with the sample removed and subsequently reinserted for each test. Once complete, the testing process was repeated again three times using the long impedance tube (1998 standard). Care was taken during the sample placement to maintain a constant distance between the sample and microphones so as to minimize the bias error.

4 RESULTS

Many sources of error and variability of the results can exist. These can include non-uniformity of the tests samples and the preparation of the same as well as inaccurate placement of the microphones. However, it is not possible to quantify the bias error of the experiment, and as such, comment of the effect of the two different tube lengths on bias error is not possible since no true reference material exists for which the true performance values are known [3] [5]. As such, a qualitative comparison of the results between the various tests for the samples are presented for both a given tube length as well as an examination between the short and long tubes. However, an examination of the results from the short and long tube is possible by comparing the variability of the data to the Repeatability Interval I(r) and Reproducibility Interval I(R)) as described in sections 11.5.1 and 11.5.2 respectively of the standard [5].

4.1 Qualitative Results

A qualitative comparison of the results for the three samples using each of the short and long tubes was conducted as was a direct comparison of the data of the short tube to the long tube. Given in Figures 3a and 3b are the results of the three tests from sample D using the short and long tubes respectively. Examination of these figures show a good correlation between the three tests for each of the two tube lengths for representative sample D. Similar results were found to also be the case for samples A through C. Given in Figure 4 is a comparison of one test of sample D using the short and long tube. While the two curves do not completely overlap at all frequencies, good correlation is demonstrated again for the results for the common test sample between the two different lengths of tubes was found. As such, little appreciable differences are evident in the results from using the short and long tubes

4.2 Results of Repeatability and Reproducibility

A more rigorous examination of the variability in the measured results can be achieved through examination of the repeatability and reproducibility intervals, *I(r)* and *I(R)*. The within- and between-laboratory precision of this test method, expressed in terms of the within-laboratory, 95 % Repeatability Interval, *I(r)*, and the between-laboratory, 95 %, Reproducibility Interval, *I(R)*, is listed in Table 1. These statistics are based on the results of a round-robin test program involving ten laboratories [3] [5].

For this study, an evaluation of the repeatability and reproducibility indexes was carried out for each sample type for each respective tube length. Illustrated in Table 2 are the absolute values of the differences between the maximum and minimum absorption results for the short and long tube measurements from sample D data. It can be seen that the differences for all the tests are within the criteria for both within- and between-laboratory precision 100% of the time. While not given, similar results indicating 100% compliance of the criteria was found for samples A through C as well for both the short and long tube configurations.

To represent a worst case scenario comparison between the short and long tubes, a study of the maximum absolute value differences using the difference between the maximum and minimum absorption values from the six overall tests for a given sample type using the short and long tube results combined was determined. These absolute values are given in Table 3 for comparison to the requirements detailed in Table 1. It can be seen that the results show a 96% repeatability index compliance and a 100% reproducibility index compliance for the test data measured. From this, it can be concluded that little difference exists in the results between the short and long tube as a result of the tube length differences. That is, the error falls within the acceptable range allowed for due to bias error alone for a given tube length design.

5 CONCLUSIONS

An investigation was carried out to determine if appreciable differences in absorption coefficient exist for two different impedance tube length designs. The short and long tube lengths are designed to meet the qualifications specified by the 1985 and 1998 versions of the ASTM E1050 standards respectively. Using the measured results for three trials of four different material types, unappreciable differences were found between the trials for each tube length as well as for the comparison of the short to the long tube length data. This was quantitatively verified through comparison of the absolute differences of absorption to the Repeatability Interval I(r) and Reproducibility Interval I(R)) criteria as given in Table 2 of the standards. All calculated differences met the required 95% criteria. From this, it can be reasonably concluded that either tube length design can be used with the expectation of valid results for absorption coefficient. Any differences in results between the two tube lengths are most likely attributed to imprecision associated with the preparation and installation of the test samples and not the impedance tube lengths.

6 REFERENCES

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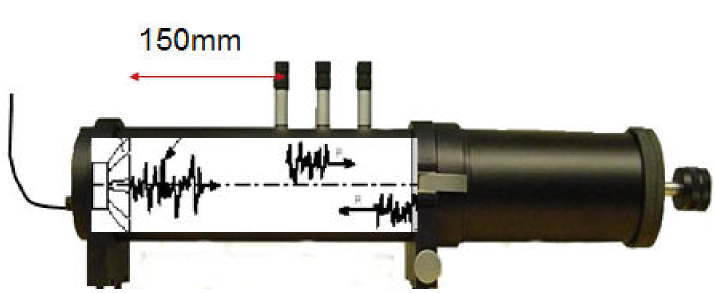

Fig. 1a –Impedance Tube with 150 mm distance Between the Source and Nearest Microphone in Meeting the 1985 Version of the ASTM E1050 Standard

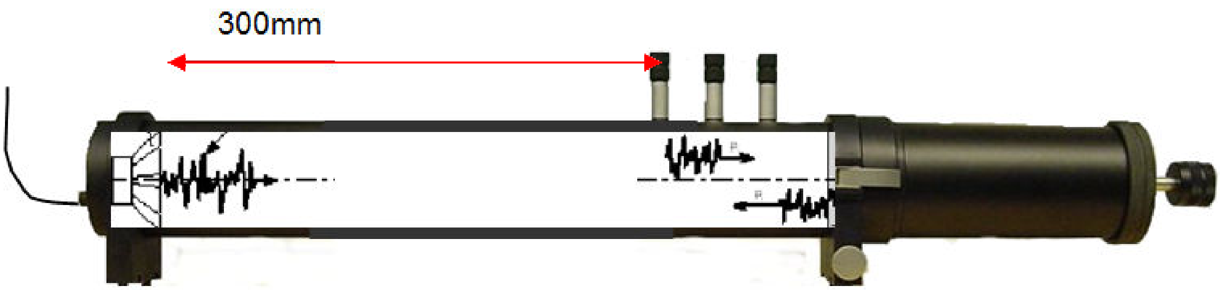

Fig. 1b –Impedance Tube with 300 mm distance Between the Source and Nearest Microphone in Meeting the Update 1998 ASTM E1050 Standard

Fig. 2 – Photos of samples used in the testing

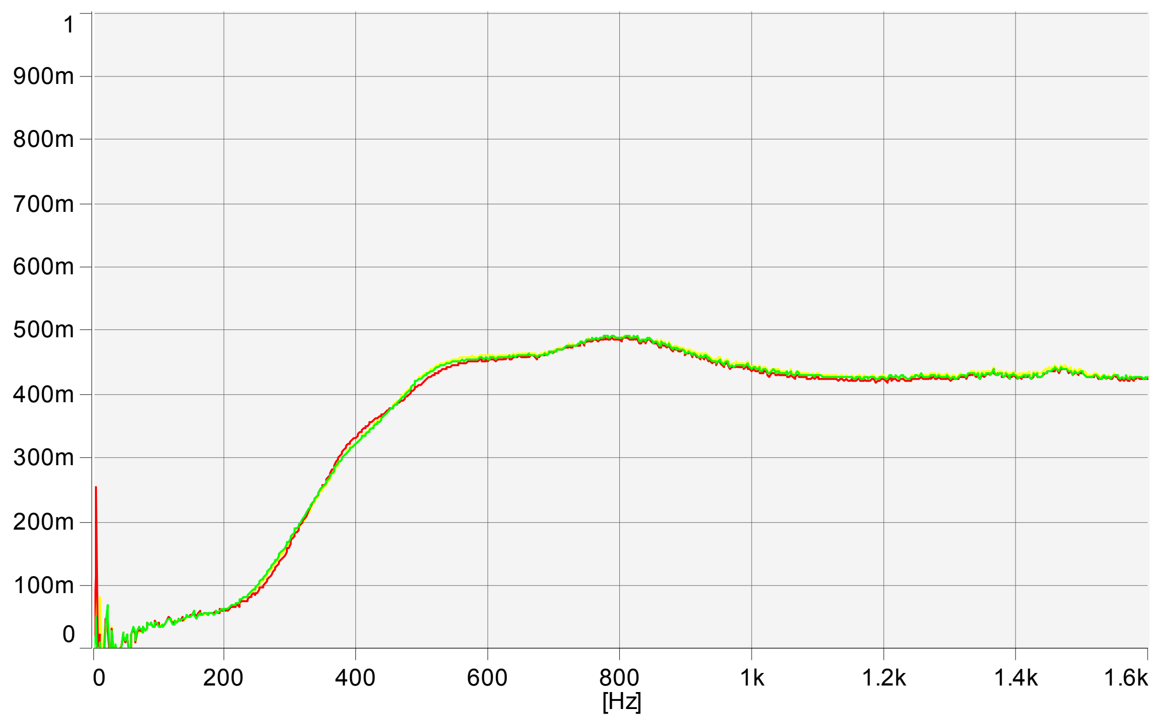

Fig. 3a –Absorption Coefficient Results For Sample D fromThree Tests Using the Short Tube

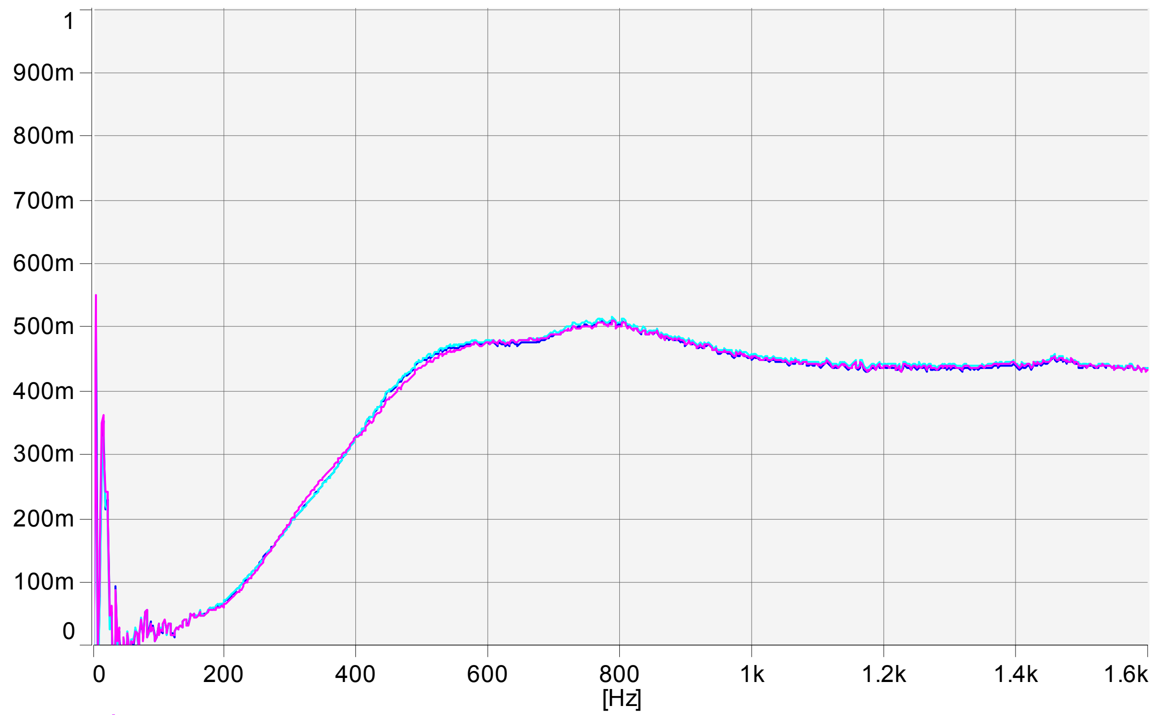

Fig. 3b –Absorption Coefficient Results For Sample D fromThree Tests Using the Long Tube

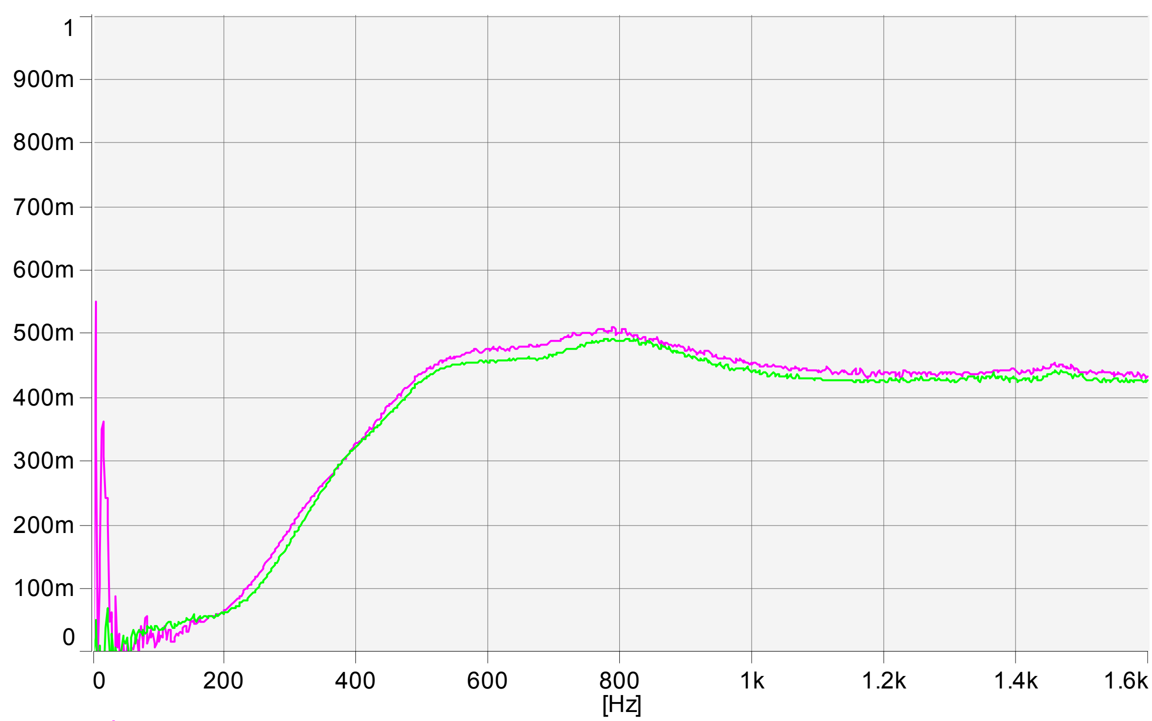

Fig. 4 –Absorption Coefficient Results For Sample D from First Test Using the Short and Long Tubes

Table 1 - Within-Laboratory Repeatability, I(r), and Between-Laboratory Reproducibility, I(R) [5]

Variable	Statistic	125	250	500	1000	2000	4000
A	I(r)	0.04	0.02	0.04	0.05	0.01	0.04
	I(R)	0.09	0.08	0.11	0.12	0.03	0.07

Table 2 - Absolute Value difference of Absorption for Sample D Using the Short and long Tubes

Frequency	125	250	500	1000
Short Tube	0.003	0.01	0.01	0.002
Long Tube	0.001	0.005	0.01	0.005

Table 3 - Absolute Value difference of Absorption for Short and long Tube Results for all Sample Types

Frequency	125	250	500	1000
Sample A	0.01	0.02	0.04	0.04
Sample B	0.009	0.01	0.01	0.05
Sample C	0.04	0.02	0.04	0.04
Sample D	0.03	0.02	0.01	0.01