Acoustic wave propagation through panels that are made of used tea bags

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1. INTRODUCTION

Tea became part of our life since 2500 B.C. Around six million tons of fermented and unfermented tea is being used by people every day across the world. Tealeaves are biodegradable but the plastic that is used to make tea bags is not recyclable or biodegradable. Conventional tea bags can't totally decompose due to its plastic content. Therefore, these plastics can cause environmental pollution. For this investigation, the tea is supposed to stay inside the original bags after being used and then washed. However, it is a common practice to seal the bags with a sort of non-poisonous glue, even though it should be said that the main brands in the UK signed the WRAP's UK Plastic Pact to get rid of all the plastic by the end of 2025 **[1].** The bags used for the project do not contain any plastic. Despite the acoustic side of the problem, where plastic could interfere with the properties of the pure material, it is important to mention that a recent preliminary study by *McGill University* in Montreal Canada **[2]**, pointed out how the plastic in tea bags leaks into the beverage leaving billions of microplastics that can be harmful for the users and the environment, further studies will have to make clear if the phenomenon is actually harmful.

According to *Wong* **[3]** Spent Tea Leaves (STL) when compressed and mixed with natural rubber latex binder present a very good resistance to fire, to termites and fungal growth, as they are rich in polyphenols (tannins). The paper shows a table comparing three types of tea, where the finest quality presents the best acoustic properties with sound absorption coefficients from 0.84 to 0.96, for the range of frequencies between 2 kHz and 4 kHz.

The statistical facts about tea show that the countries where people drink more tea are different from the ones actually producing it the most. According to *FAOSTAT* **[4]** the global annual production in 2019 (most recent available) was of 6.101.062 tons with a global market size of nearly 50 billion of U.S dollars, 18 of which only regarding China. In-fact China seems to be massively more important compared to the rest of the list when comes to tea production, probably due to its ideal mild climate. Substantially the countries where tea farming has had the longest trading history like China, India and Kenya, continued to see tea production a very advantageous market. An interesting fact from the website *statista* **[5]**, reports that Turkey manages to be one of the top six countries producing tea, but when observing its consumption, appears to be first with almost seven pounds pro-capite in 2016, well much more compared to other countries, meaning that the Turkish production is mainly due for the local consumption. Ireland and UK confirm their tea drinking tradition as expected.

2. PANELS MADE OF USED TEA BAGS

The project, as well as the acoustic performance of the material, explored the production side of the panels to better understand the potential and main difficulties that might occur.

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2.1 Preparation

The activity started collecting as many used tea bags as possible through a public Café. 400 tea bags were collected through public Café. Collected tea bags were washed and then dried. However, this could be optimised if implemented on a large scale with the help of industrial facilities and equipment, such as dryers. In order for the panels to be assembled, the tea bags have been rolled (see Figure 1), two panels 40cm x 40cm x 7.5cm were built and each panel needed about 1300 units to be completed.

Figure 1: Preparation process

Particular attention is required for the product to be dried as mould would spread and ruin the whole panel and when assembling it is important to keep the surface as uniform as possible, with no gaps between bags. The total weight of the panel was 3.016 kg, keeping out the weight of the frame of 0.7576 kg the tea would weight 2.2584 kg, giving a density of circa 208.5 kg/m^3.

2.2 Measurements

For the purpose, three different measurement procedures were used, determining the sound absorption coefficient (α) and transmission loss (TL) of various samples with the use of an impedance tube and an impedance gun.

2.2.1 Sound absorption using impedance tube

A sample of test material with a movable rigid backing is placed at one end of a tube and a loudspeaker is placed at opposite end of the tube. Two ¼ inch microphones were mounted into a microphone grid at positions along the length of the impedance tube (as indicated in Figure 2), with each microphone grid being sealed tight to its housing. The microphones were fed to a four-channel data acquisition card (type MC3242, BSWA Tech.) which was connected to a computer for logging and further analysis. The acoustic sound field, an incident plane sinusoidal wave, P_i was created by a loudspeaker with a built-in amplifier. The transfer function method is used to determine the acoustical properties of the sample whereby the sound pressure at two fixed microphone locations within the tube is measured and then used as input for the acoustic transfer function to calculate the absorption coefficients 6-7].

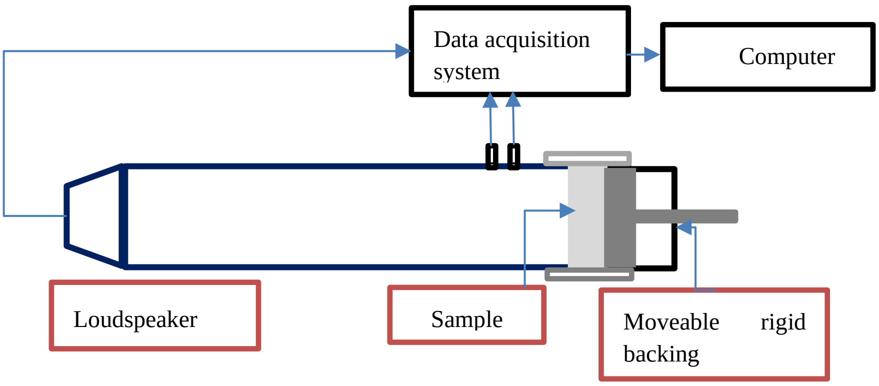


Figure 2: Impedance tube system [7].

The specimen used for the measurements (see Figure 3) was of two sizes, one of 17mm and a second one of 70mm.

Figure 3: Tea bags samples

Table 1: The samples have been combined also together with air gaps, to cross reference more results.

N	Sample composition mm	Tea sample layer	Empty space layer	Tea sample layer	Total length mm
1	17	17			17
2	17-36-17	17	36	17	70
3	17-66-17	17	66	17	100
4	17-116-17	17	116	17	150
5	70	70			70
6	70-13-17	70	13	17	100
7	70-30	70	30		100
8	70-63-17	70	63	17	150
9	70-80	70	80		150

2.2.2 Sound absorption measurement using an impedance gun

The impedance gun method is defined as an *In-Situ method*. Although *BS 13472-1-2* **[8]** specifies the *In-Situ* technique for road surfaces, this method does not have a dedicated British Standard, therefore the measurement was made following the gun's manual **[9]**. The core of the system is a platinum mini sensor (see Figure 4), able to measure the *velocity* and the *pressure* in the very same position in space, being particularly accurate at high frequencies, having a sensitivity range from 10 nm/s to 1 m/s. TWhite noise is generated towards the material mounted on a rigid surface using a sound source at 23 cm from the probe. The impedance gun is equipped with a system designed to decouple the sensors from structure born vibration generated by the spherical loudspeaker. The sound pressure and acoustic particle velocity are measured directly on the surface of the material. The absorption and reflection coefficient can be obtained directly from the measured impedance as the complex ratio of sound pressure to particle velocity [10].

Figure 4: Impedance gun measurement

2.2.3 - Transmission loss measurements using the impedance tube

Measurements have been carried out in a circular impedance tube with an internal diameter of 100 mm (see Figure 5). A sample of test material is placed at the middle of a tube. A loudspeaker is placed at one end of the tube and a rigid plate is placed at the opposite end of the tube. Six ¼ inch microphones (three microphones on each side of the test sample) were mounted into microphone grid at positions along the length of the impedance tube. Each microphone grid was sealed tight to its housing. The microphones were fed to a four-channel data acquisition card (type MC3242, BSWA Tech.) which was connected to a computer for data analysis. The acoustic sound field, an incident plane sinusoidal wave, P_i was created by a loudspeaker that was fed with a power amplifier with build-in pink noise generator (type PA50, BSWA Tech.). The sound signals at four fixed microphone locations within the tube were simultaneously measured. Microphones 1 and 3 for upstream tube and 4 and 6 for downstream tube are used to measure the transmission loss between 63 Hz and 500 Hz while microphones 2 and 3 for upstream tube, and 4 and 5 for downstream tube are used to measure the TL of noise barriers between 250 Hz and 1600 Hz. The VA_LAB using Transfer Function Method separates the incident and reflected energy from the measured transfer function, and then estimates the acoustic properties of the tested sample installed in the tube [7].

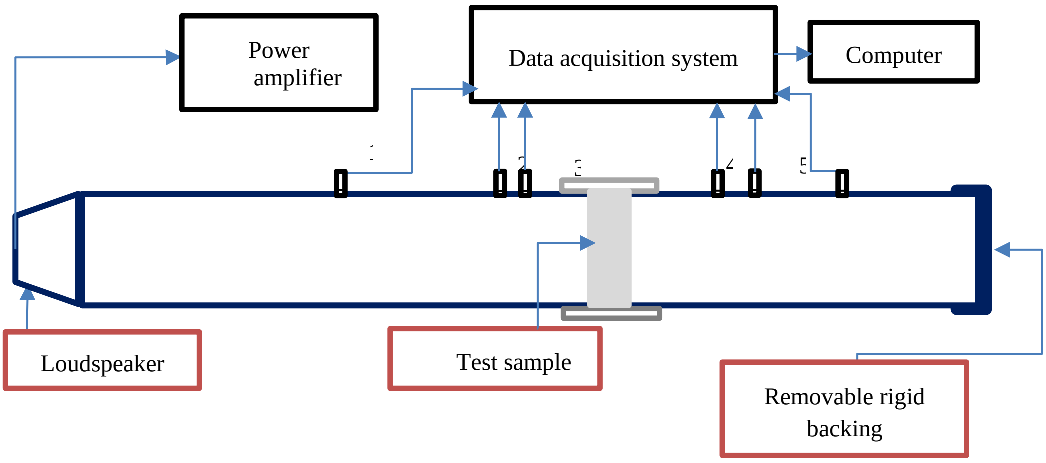
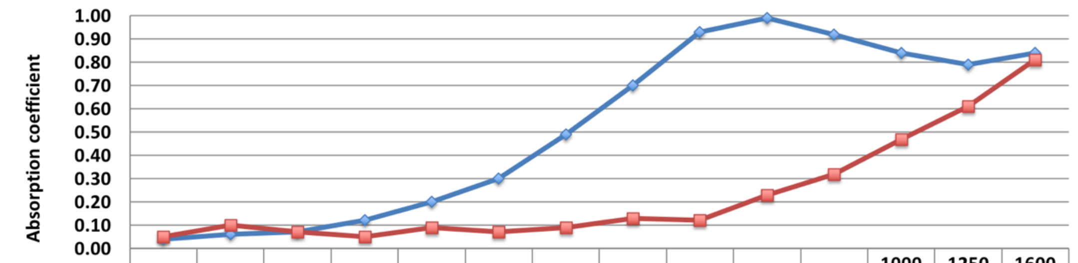


Figure 5: Impedance tube TL configuration [7].

2.3 Measurements results

2.3.1 Impedance tube

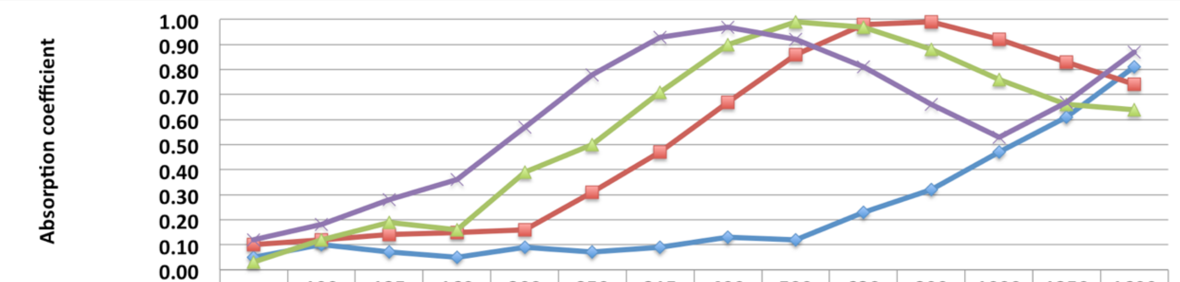
Measured absorption coefficients of 17 mm and 70 mm thick samples are given in Figure 6. 17 mm thick panel is effective only above 500 Hz while 70 mm thick sample gives higher absorption coefficient at mid and higher frequencies. The peak absorption for 70 mm thick sample is around 0.99 at 630 Hz.



	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz
α 70 mm	0.04	0.06	0.07	0.12	0.20	0.30	0.49	0.70	0.93	0.99	0.92	0.84	0.79	0.84
α 17 mm	0.05	0.10	0.07	0.05	0.09	0.07	0.09	0.13	0.12	0.23	0.32	0.47	0.61	0.81

Figure 6: Absorption coefficients of 17 mm and 70 mm panels.

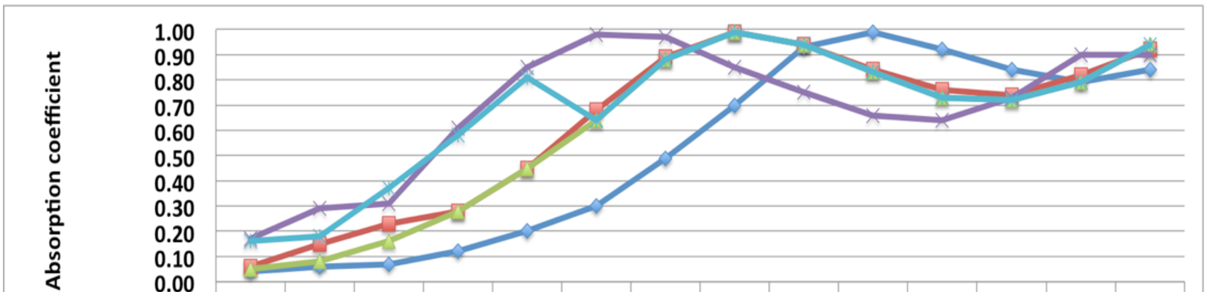
More samples combinations were measured in order to investigate the space optimisation of a hypothetical multi-layered panels. It can be directly noticed in Figure 7 how using two 17mm samples separated by air cavity increases the sound absorption performance at lower frequencies. It seems that increasing air cavity between samples increases sound absorption performance throughout frequency range while shifting maximum pressure areas to lower frequency.



	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz
α 17 mm	0.05	0.10	0.07	0.05	0.09	0.07	0.09	0.13	0.12	0.23	0.32	0.47	0.61	0.81
α 17-36-17 mm	0.10	0.12	0.14	0.15	0.16	0.31	0.47	0.67	0.86	0.98	0.99	0.92	0.83	0.74
α 17-66-17 mm	0.03	0.12	0.19	0.16	0.39	0.50	0.71	0.90	0.99	0.97	0.88	0.76	0.66	0.64
α 17-116-17 mm	0.12	0.18	0.28	0.36	0.57	0.78	0.93	0.97	0.92	0.81	0.66	0.53	0.67	0.87

Figure 7: Absorption coefficient for different combinations.

A similar approach has been applied to the 70mm sample, being combined with air cavity and a 17mm sample. These combinations (see Figure 8) present a similar behaviour in relation to increasing air gap and sound absorption, in particular the combination 70-30 and 70-13-17 gives similar results because they have same combined thickness. This proves that increasing sample thickness and/or adding an air cavity between the sample and rigid backing would increase low and mid frequency performance of tee-bag panels.

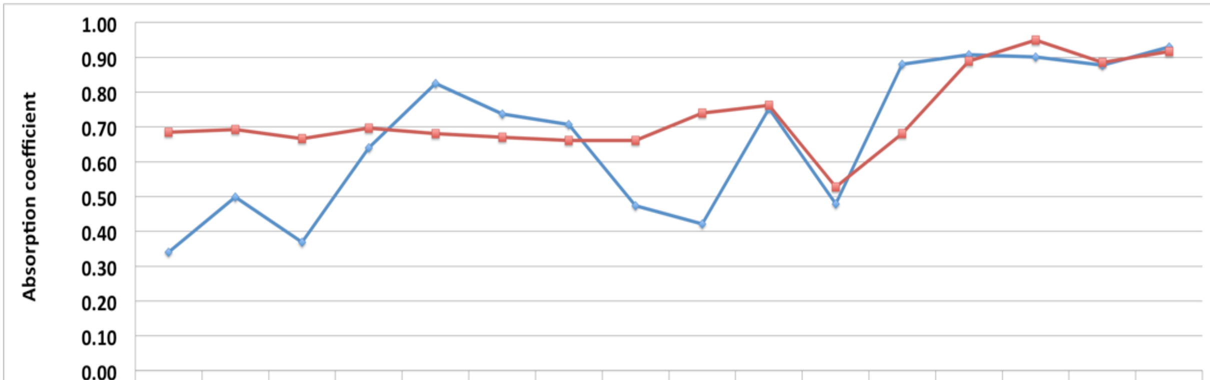


	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz
α 70 mm	0.04	0.06	0.07	0.12	0.20	0.30	0.49	0.70	0.93	0.99	0.92	0.84	0.79	0.84
α 70-13-17 mm	0.06	0.15	0.23	0.28	0.45	0.68	0.89	0.99	0.94	0.84	0.76	0.74	0.82	0.92
α 70-30 mm	0.05	0.08	0.16	0.28	0.45	0.64	0.88	0.99	0.94	0.83	0.73	0.72	0.79	0.94
α 70-63-17 mm	0.17	0.29	0.31	0.61	0.85	0.98	0.97	0.85	0.75	0.66	0.64	0.73	0.90	0.90
α 70-80 mm	0.16	0.18	0.37	0.58	0.81	0.64	0.88	0.99	0.94	0.83	0.73	0.72	0.79	0.94

Figure 8: Absorption coefficient of 70 mm thick sample with five different combinations.

2.3.2 Impedance gun

Absorption coefficient of tea-bag panel measured in anechoic chamber and in normal laboratory conditions using impedance gun method are presented in frequency domain in Figure 9. There is very good similarity between both results above 630 Hz while some discrepancies have been observed at low frequencies. This might be because of higher background noise in the laboratory and/or the sound in the laboratory might be reverberant. Another reason might be that impedance gun response might be limited at lower frequency end.



	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1000Hz	1250Hz	1600Hz	2000Hz	2500Hz
Lab α	0.34	0.50	0.37	0.64	0.82	0.74	0.71	0.47	0.42	0.75	0.48	0.88	0.91	0.90	0.88	0.93
Anechoic α	0.69	0.69	0.67	0.70	0.68	0.67	0.66	0.66	0.74	0.76	0.53	0.68	0.89	0.95	0.88	0.92

Figure 9: Absorption coefficient of tea-bag panel measured in anechoic chamber and laboratory condition using Impedance gun.

2.3.3 Transmission, TL measurements

Measured Transmission Loss TL of two tea-bag panels are compared in Figure 10. TL of both panels increases throughout frequency range. 70 mm panel give up to 9.6 dB attenuation at 1600 Hz while 17 mm panel attenuate sound pressure level up to 4.7 dB at 1600 Hz.

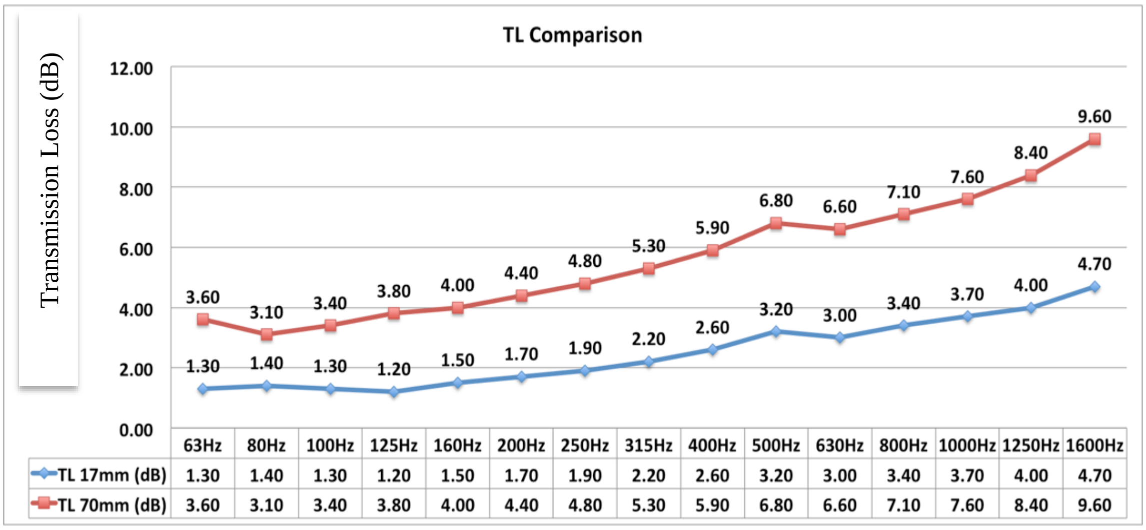


Figure 10: A comparison of Transmission Loss for two tea-bag panels in frequency domain.

3. CONCLUSIONS

Sound absorbing panels that are made of tea bags were designed and developed to investigate their applications in architectural and building industry. Acoustical properties (sound absorption and transmission loss) of 17 mm and 70 mm thick panels were investigated using transfer function method and impedance gun technique. Results show that 70 mm thick panels give an absorption coefficient higher than 0.8 between 500 Hz and 1600 Hz while 17 mm thick panels give an absorption coefficient that is mostly effective at higher frequencies. Up to 9 dB sound transmission loss is obtained at some frequencies.

4. ACKNOWLEDGEMENTS

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