Experimental Investigation on the Effect of Origami Geometry on the Acoustic Characteristics

NURUL FARHANAH MUARAT, MOHAMED HUSSEIN, RAJA ISHAK RAJA HAMZAH, ZAIR ASRAR AHMAD, MOHD ZARHAMDY MD ZAIN, *NORASIKIN MAT ISA and MAZIAH MOHAMAD

Department of Applied Mechanics, Faculty of Mechanical Engineering Universiti Teknologi Malaysia 81310, Johor Bahru, Johor MALAYSIA

*Dept. of Plant and Automotive Engineering Faculty of Mech. and Mfg. Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor MALAYSIA

nfarhanah8@live.utm.my, mohamed@fkm.utm.my, rishak@fkm.utm.my, zair@fkm.utm.my, zarhamdy@fkm.utm.my, sikin@uthm.edu.my, maziah@fkm.utm.my

Abstract: Preliminary investigation was conducted to explore the practicability of utilising deformable origamic material in varying room acoustic characteristic. Investigation was performed in a reverberation room to investigate the variation of the origami geometries and their effect to the reverberation time and sound absorption coefficient. Two different geometric origami were presented in this investigation. The experiment was undertaken in accordance to ISO 354:2003 Measurement of Sound Absorption in a Reverberation Room. The results show that there is correlation between variations in the origami geometries with the acoustics characteristics.

Key-Words: Origami, Foldcore Structures, Reverberation Time, Sound Absorption Coefficient

1 Introduction
In acoustics halls, various strategies have usually been implemented in an effort to provide an optimum reverberation required suitable for different type of events. Such strategies commonly focus on varying the absorption coefficient and hall volume as well as the introduction of diffusers [1]. These strategies are used to control the reverberation time as the reverberation time has always been the major acoustics parameters to determine the sound quality of the halls [2]. According to the Sabine equation, reverberation time is dependent on the volume and the total absorption of the hall [3]. Thus, to provide an adjustable reverberation time, one should be able to control the parameters that affecting the reverberation time.

A parametric survey conducted on the wooden rectangular periodic groove structure (Figure 1) has shown that the structure with its groove filled with porous material can provide adjustable absorption properties by changing the parameters of the structure such as height of the groove, length of the period surface and depth of the porous material[4]. Therefore, if the absorption of the wooden structures can be adjusted by changing its parameters, it would be very beneficial especially if the structure is deformable and the absorption properties can be adjusted to accommodate various acoustics requirements. Since the wooden structure is rigid, this paper proposed a technique to provide adjustable absorption by using geometric origami. It is known that origami term is originated from Japanese word and the concept of origami is by folding a flat sheet to form a 2D and 3D shape [5]. According to the review by Sebastian Heimbs, the origami concept has been used in the aerospace industry and automotive and it is called ‘foldcores’ structure (Figure 2). The application of the foldcores structures are widely used in sound absorption application and to improve strength [5].

Figure 1: Wooden Rectangular Periodic Groove Structure [4]
The advantage of the origami structure is that it can be deformed which means that the shape can change its geometric conditions dynamically whereas the wooden rectangular periodic groove structure is rigid. Therefore, this paper investigates whether the origami shapes are capable to provide adjustable reverberation time and sound absorption coefficient by changing its geometric conditions.

2 Origami Specification
Two different types of geometric origami have been used in the research works as shown in Fig. 3 and Fig. 4. They are of triangle and zigzag geometry. The two geometries were folded by using 1200 gsm chip boards. Each of them has different configurations due to different geometry. To form a large specimen, several of them were joined with white glue. Practically, origami is deformable where the dimensions of the geometries (length, width, height and surface area) are changed when it is being pulled or compressed. For example, when the triangle geometry (see Fig. 3) is pulled, parameter $x$, $h$ and the surface area of the triangle geometry changed while $z$ maintain the same. Similarly, when the zig-zag geometry is pulled (see Fig. 4), the parameters that changed were $x$, $h$ and the surface area but the length of $y$ and $z$ remain the same.

3 Measurement Method
The purpose of the study is to investigate the relationship between variation of origami’s geometries and changes of reverberation time and sound absorption coefficients. Measurement of sound absorption coefficients had been conducted in the reverberation room at Faculty of Mechanical Engineering, UTM. The reverberation room has a volume of 54.65 m$^3$ and a Schroeder frequency of 500 Hz; which means that there is no absorption takes place below 500 Hz [7]. Although the room volume did not meet the ISO 354 requirement, the measurement technique employed is in accordance to ISO 354:2003 [8].

3.1 Measurement Procedure
Following the ISO 354:2003 “Measurement of Sound Absorption Coefficients in Reverberation Room”, the two geometric origami are used as the specimen which their absorption coefficients were to be determined. The specimen is placed at the floor of the reverberation room and the measurements of the reverberation time were measured by exciting the room with balloon bursts. The excitation of the balloon bursts were recorded by a Solo 01dB Sound Level Meter from two different microphone locations. The microphones are 1.5m apart and the distance of the specimen to the microphones is 1m. First, the reverberation time of empty room (without any specimen) was recorded. Then reverberation times of the triangle and zig-zag origami specimens were the measured with various configurations. Each measurement was repeated four times and the reverberation time were then averaged for the two different microphones positions. The temperature and humidity throughout the measurement were approximately 26°C and 78% respectively.

3.2 Test Specimen Configuration
It is known that, area of the reverberation room surface covered by the specimen has influence on reverberation time. The surface area covered and the reverberation time is inversely proportional to each other [3]. In this study the objective is to investigate whether variation of the origami’s geometries have effect on the reverberation time and sound absorption coefficient. Therefore, the total surface area covered by the specimens in the experiment is maintained so that the area covered will not affecting the reverberation time.

Several configuration were used in the experiment for both triangle and zig-zag origami geometry and the configurations of both geometric origami are
tabulated in Table 3 and Table 4 respectively. Fraction of the specimens were removed from one configuration to another in order to maintain the surface area covered. This is clearly presented in the tables.

**Table 3: Dimension of triangle geometric origami with several configurations**

<table>
<thead>
<tr>
<th>Test Configuration</th>
<th>h (cm)</th>
<th>x (cm)</th>
<th>z (cm)</th>
<th>Surface Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration 1</td>
<td>22</td>
<td>37</td>
<td>28</td>
<td>3.34</td>
</tr>
<tr>
<td>Configuration 2</td>
<td>18</td>
<td>42</td>
<td>28</td>
<td>3.34</td>
</tr>
<tr>
<td>Configuration 3</td>
<td>14</td>
<td>47</td>
<td>28</td>
<td>3.34</td>
</tr>
<tr>
<td>Configuration 4</td>
<td>10</td>
<td>52</td>
<td>28</td>
<td>3.34</td>
</tr>
</tbody>
</table>

**Table 4: Dimension of zig-zag geometric origami with several configurations**

<table>
<thead>
<tr>
<th>Test Configuration</th>
<th>h (cm)</th>
<th>x (cm)</th>
<th>y (cm)</th>
<th>z (cm)</th>
<th>Surface Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration 1</td>
<td>23</td>
<td>31</td>
<td>21.5</td>
<td>28</td>
<td>3.34</td>
</tr>
<tr>
<td>Configuration 2</td>
<td>21</td>
<td>33</td>
<td>21.5</td>
<td>28</td>
<td>3.34</td>
</tr>
<tr>
<td>Configuration 3</td>
<td>17</td>
<td>36</td>
<td>21.5</td>
<td>28</td>
<td>3.34</td>
</tr>
<tr>
<td>Configuration 4</td>
<td>15</td>
<td>38</td>
<td>21.5</td>
<td>28</td>
<td>3.34</td>
</tr>
<tr>
<td>Configuration 5</td>
<td>13</td>
<td>40</td>
<td>21.5</td>
<td>28</td>
<td>3.34</td>
</tr>
</tbody>
</table>

3.3 Method of Calculation

The sound absorption coefficients were calculated based on the measured reverberation times in the reverberation room with and without the specimen in accordance to the ISO 354:2003 [8]. The equations used to calculate the reverberation times for both conditions are given in Eq. (1) and Eq. (2) below.

\[ A_1 = \frac{55.3V}{cT_1} - 4Vm_1 \]  

(1)

where, \( A_1 \) is the equivalent sound absorption area for empty reverberation room (m²), \( V \) is the volume of reverberation room (m³), \( c \) is speed of sound in air (m/s), \( T_1 \) is the reverberation time of the empty reverberation room (s), \( m_1 \) is the power attenuation coefficient (m¹) at temperature of the reverberation room according to ISO 9613-1 [9].

\[ A_2 = \frac{55.3V}{cT_2} - 4Vm_2 \]  

(2)

where, \( A_2 \) is the equivalent sound absorption area for reverberation room when the specimen has been introduced (m²), \( V \) is the volume of the reverberation room (m³), \( c \) is speed of sound in air (m/s), \( T_2 \) is the reverberation time of the empty reverberation room (s), \( m_2 \) is the power attenuation coefficient (m¹) at temperature of the reverberation room when specimen has been introduced.

Finally, the absorption coefficients, \( \alpha_s \), were calculated by dividing the total equivalent sound absorption area with the surface area covered by the test specimen

\[ \alpha_s = \frac{A_2 - A_1}{S} \]  

(3)

4 Result and Discussion

The results presented were in 1/3 octave band frequency as specified by ISO 354:2003. There are two parameters that were investigated which are reverberation times and sound absorption coefficients. The evaluation decay range of reverberation times was T60 and evaluated by Solo Sound Level Meter. Since the Schroeder Frequency of the reverberation room is 500 Hz, the discussions focus on the results of the test above this frequencies range.

4.1 Effect of Origami’s Geometry Variation on the Measured Reverberation Time

Figure 5 shows the effect of geometry changes on the reverberation time for triangle geometric origami. Significant difference can be observed when the specimen is deformed from one configuration to another.

Huge reverberation time difference is observed between the empty room and Configuration 1 (maximum h and minimum x). It can further observed that as the triangle geometry reduced in h (i.e. increased in x), the reverberation time at high frequencies are increased and shifted closer to the reverberation time of empty room. Overall, the reverberation time can be varied between 1s to 1.5s especially at high frequency range.
Fig. 5: Reverberation time of various triangle geometric origami configurations at 1/3 octave band frequency

Fig. 6: Reverberation time of various zig-zag geometric origami configurations at 1/3 octave band frequency

Fig. 7: Sound absorption coefficients of triangle geometric origami at 1/3 Octave Band Frequency

Fig. 7: Sound absorption coefficients of triangle geometric origami at 1/3 Octave Band Frequency
Meanwhile, the effect of the varying the zig-zag geometry shows similar variation of reverberation time as shown in Fig. 6. As the geometry changed from Configuration 1 to Configuration 5, it was observed that, as the geometry parameter $h$ increases and $x$ decreases, the reverberation time increases. However, the difference between the configurations are smaller as compared to the triangle geometric origami configurations.

4.2 Effect of Variation of Origami Geometry on Sound Absorption Coefficient

The results of sound absorption coefficients were calculated by using Eq. (3) and presented in 1/3 octave band frequencies [8]. The variation of sound absorption coefficients (Fig. 7) shows a clear difference at high frequencies when the triangle geometric origami is changed from Configuration 1 to Configuration 4. The sound absorption coefficient decreases as the height $h$ of the triangle origami increases. Based on the results, the absorption coefficients varied between approximately 0.1 and 0.3.

Fig. 8 shows that the zig-zag geometric origami also shows remarkable variation of sound absorption coefficient when the geometry is changed from Configuration 1 to Configuration 5. The absorption coefficient varies between 0.1 and 0.4 at high frequencies.

Overall, the results of the two geometric origami, show good trends for frequencies 2 kHz and above meanwhile for frequencies below 2 kHz the trends are inconclusive. In addition to this, the trends are worst at low frequencies range. These are probably due to the small volume of the reverberation room (54.65 m³) which unable to cover absorption at low frequencies range and are inappropriate to analyze due to accuracy problem [7]. Besides that, the Schroeder frequency of the room is 500 Hz which indicates that no absorption will take place below this frequency [7].

5 Conclusion

Two types of origami geometries have been tested in a reverberation room to provide a better understanding of the relationship between the variation of origami’s geometries with reverberation characteristics as well as sound absorption coefficients. The present preliminary work provides good correlation between the variations of origami geometries with the acoustic characteristics. Therefore, based on this experimental investigation, it can be concluded that while surface area covered by the specimen is maintained throughout the whole measurement, the variation of parameter $h$ and $x$ contributed to the change of reverberation time and sound absorption coefficient at high frequencies of above 2 kHz.

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References:


