

# COMPARISON OF NORMAL INCIDENT SOUND ABSORPTION COEFFICIENT OF DIRECT PIERCING CARVED WOOD PANEL FOR CIRCULAR, GEOMETRY AND FLORAL DESIGN

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## Abstract

Direct Piercing Carved Wood Panel (DPCWP) is among the famous Malay wood carving art in the Malay culture. It is the best example of Malay people's creativity and masterpiece. In this paper, the comparison of normal incidence sound absorption coefficient,  $\alpha_n$  (SAC) for three major types of design for the DPCWP is discussed. The simplest form of DPCWP, the circular type, then the geometry and floral types were investigated based on simulation and measurement works using sound intensity method to determine the normal incidence SAC, for 30% and 40% perforation ratios. The simulation work was carried out by using BEASY Acoustic software based on Boundary Element Method (BEM). From the results, there is an identical trend for DPCWP with geometry and floral design from 250 Hz to 4 kHz. At high frequencies (1 kHz to 4 kHz), both design show the tendency of decrement, suggesting that the complexity of the design does affect the average SAC value. However, for circular design, SAC is higher than other design at 1 kHz and shows a similar trend with other design at 2 kHz and 4 kHz for both simulation and measurement result.

**Keywords:** Normal incidence sound absorption coefficient, direct piercing carved wood panel, sound intensity method, Boundary Element Method

## Abstrak

Ukiran kayu tebuk terus adalah antara ukiran Melayu terkenal di dalam kebudayaan Melayu. Ianya adalah contoh terbaik bagi seni karya dan kreativiti kaum Melayu. Di dalam kertas ini, perbezaan kadar penyerapan bunyi sudut tuju normal untuk tiga jenis rekabentuk ukiran kayu telah dibincangkan. Antaranya ialah ukiran kayu rekabentuk bulatan, iaitu rekabentuk yang paling mudah, kemudiannya ukiran kayu rekabentuk geometri dan bercorak tumbuh-tumbuhan telah dikaji berdasarkan kaedah simulasi dan kaedah pengukuran menggunakan kaedah pengamatan bunyi bagi kadar tebukan 30% dan 40%. Kaedah simulasi telah dijalankan menggunakan perisian BEASY berdasarkan kaedah unsur sempadan. Dari keputusan kajian, terdapat persamaan bagi ukiran kayu bercorak geometri dan tumbuh-tumbuhan antara frekuensi 250 Hz hingga 4000 Hz. Di frekuensi tinggi (1000 Hz – 4000 Hz), kedua-dua rekabentuk menunjukkan penurunan, mencadangkan bahawa rekabentuk yang kompleks mempengaruhi nilai purata kadar penyerapan bunyi. Walaubagaimanapun, untuk corak bulatan, kadar penyerapan bunyi adalah lebih tinggi jika dibandingkan dengan rekabentuk yang lain di frekuensi 1000 Hz dan menunjukkan persamaan di frekuensi 2000 Hz dan 4000 Hz bagi kedua-dua kaedah simulasi dan pengukuran.

**Kata kunci:** Kadar penyerapan bunyi sudut tuju normal, ukiran kayu tebuk terus, kaedah pengamatan bunyi, kaedah unsur sempadan

## 1.0 INTRODUCTION

The direct piercing carved wood panel (DPCWP) is among the famous Malay wood carving art in the Malay culture. Since over hundred years ago, this kind of art has been introduced to Malay people based on the development of Islamic architecture that have been brought from West Asia [1]. Since hundreds of years ago the DPCWP has been used widely in Malay structure and buildings [2]. The DPCWP, which can be in various shapes and size of the aperture, is not only allowing fresh air circulation and providing thermal comfort inside the building, but also has the ability to allow sound energy to pass through. Thus, it is believed that it can act as sound absorption material. Previous studies have shown that DPCWP with certain design can absorb sound energy more than 50% of speech frequencies [3-4]. However the DPCWP design complexity has the relationship with the performance of sound absorption rate at certain frequencies. For example, the geometry design has symmetrical apertures with sharp edges while floral design is totally different with curvy and different dimension of aperture. The complexity of design is believed affects the sound absorption performance for DPCWP. The usage of DPCWP as part of the building and the structure is decreasing and replaced by high cost materials such as glasses, carbon fibers and fabrics that cover most of the building's surface. However, mostly DPCWP is used as door, wall and window's partition as decoration materials. Modern materials, require extra cost for installation and maintenance work, and also need more energy to provide thermal comfort.

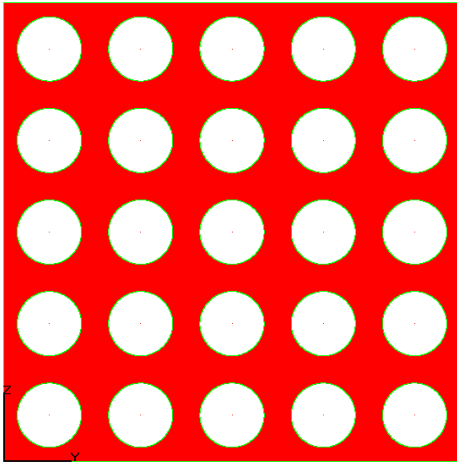
In the first section of this paper, the DPCWP with circular, geometry and floral design have been reviewed briefly. The experimental work using sound intensity method, and simulation work based on Boundary Element Method (BEM) were discussed. Finally, the discussion of experimental and simulation results are presented.

### 1.1 DPCWP with Circular, Geometry and Floral Design

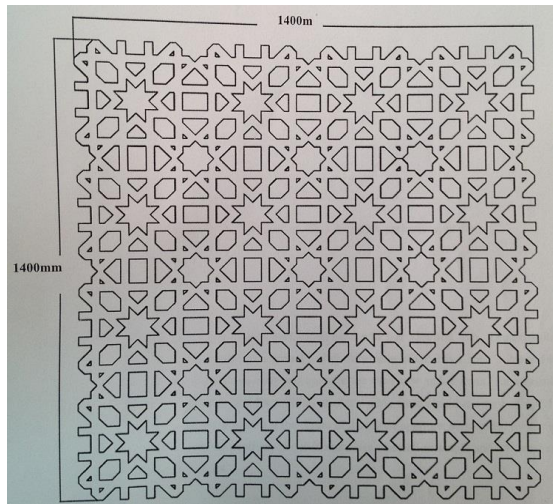
The selected DPCWPs for this research were based on three typical designs, the circular, geometry and floral pattern. The circular design is the simplest form of wood carving motif, exist in multiple circular apertures with symmetrical arrangement and uniform diameter. The geometry design is basically based on the critical thinking and ideas expressed by mathematicians. The characteristics of geometry pattern are the symmetrical shape and repetition element contribute to the complexity and beautiful patterns. The advantages of this design are the independent scale and applicable in most types of materials suitable either for exterior or

interior of a building. The basic shapes of geometry pattern can be described in the form of circular, square, triangle, pentagon, hexagon and octagon, also in frequent star-shaped are elaborated with multiplication, repetition and rotation usually in a symmetrical arrangement [5]. In Malaysia, one of the most beautiful and popular design in wood carving is the floral pattern. The floral design is the expression by the wood carver based on the nature of floral that can be found in their living areas by drawing and carving the recognized floral elements to their wood carving product. Any competent wood carver can interpret and generate such intricate floral elements in their product based on his/her own inspiration. The interesting part is, a good wood carver can redraw the floral element and even makes it more attractive by adding their own styles and techniques to the wood carving product so that the wood carving product should be so beautiful and has many striking features compared to the actual floral elements. The purpose of the selection of these designs in this study is to investigate and to understand the sound absorption performance for DPCWP with various design and style.

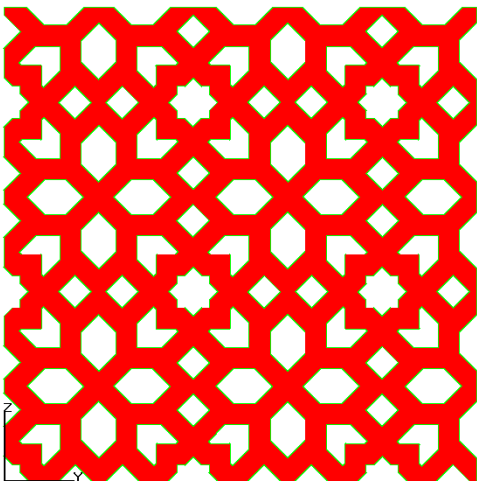
The perforation ratio was set to 30 % and 40 % for all motifs for simulation and experimental works. Clearly, 30% and 40% perforation ratios were selected for comparison since these ranges are the closest perforation ratios available for all design. The perforation ratios for all original design were basically around 25%-30%. The design was redrawn using CAD software and all apertures were adjusted for 30% and 40% perforation ratios. For circular pattern, two DPCWPs with different perforation diameter were selected for investigation. Figure 1 shows an example of DPCWP with a circular design for simulation work using BEASY. For geometry design, two different patterns and styles were selected for 30% and 40% perforation ratio. Figure 2 shows the design for DPCWP with geometry pattern with 30% perforation ratio, consists of eight pointed stars in the middle of each single unit, surrounded by a group of diamond shape aperture, and some small triangles and square shape. Figure 3 shows the design of DPCWP with geometry design with 40% perforation ratio. The DCWCP for geometry design with 40% perforation ratio is simpler than the 30% perforation ratio. It consists of eight pointed stars in relation to the square grid at the center of each single unit, and surrounded by diamond shape and rotating arrows.



**Figure 1** Example of DPCWP with circular design in BEASY Acoustic software

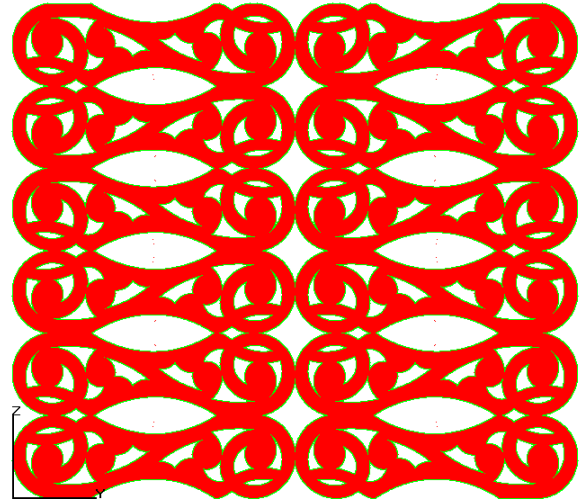


**Figure 2** DPCWP with geometric design with 30% ratio



**Figure 3** DPCWP with geometric design with 40% perforation ratio

For DPCWP with floral design, both perforation ratios are based on *Daun Sireh* pattern. It consists of 16 different styles of aperture in one single pattern. These 16 apertures come from 8 different shapes and sizes of aperture which have been mirrored from one side to another. Figure 4 shows the DPCWP with floral pattern with 40% perforation ratio in BEASY Acoustic software.



**Figure 4** The DPCWP with floral design with 40% perforation ratio in BEASY Acoustic software

## 2.0 METHODOLOGY

The comparison of sound absorption coefficient,  $\alpha_n$  (SAC) results for DPCWP with circular, geometry and floral design were based on sound intensity method and simulation method by using BEASY Acoustics software.

### 2.1 Sound Intensity Method

The sound intensity method is a powerful technique to investigate the sound power and sound absorption coefficient, depending on sound energy density. A p-p probe was used to measure the flow of the active intensity on the material's surface to calculate the sound power and sound absorption coefficient. This is a faster and easier way to measure the intensity on the material's surface in the reverberation room to overcome the non-diffuse sound fields and sound diffraction problems [6]. The parameters for the sound intensity method were including the intensity reference level, the selection of the microphone spacer between the p-p probe, the sampling type and also the measurement distance. The standard SI unit for the sound intensity technique measurement is in decibel unit (dB). Based on the free field relation, the intensity reference level have been approximately measured and in this sound intensity measurement work, it was assumed that the resulting dB reading on the sound

intensity equipment was based on the propagation of waves directly from the sound source and travel vertically and perpendicular to the surface of the DPCWP. The value of the reference level of sound intensity,  $I_0$  is described as

$$I_0 = 1 \times 10^{-12} \text{ W/m}^2 \quad [1]$$

The selection of the spacer in this measurement work is so critical to minimize such problems, including the phase mismatch error and to ensure accurate reading during the measurement work. [7]. A 12 mm microphone spacer was selected as it has high frequency limitation up to 5 kHz [9]. The microphone spacer distance of 12 mm was applicable for the octave frequency selected for this research work, which are 250 Hz, 500 Hz, 1 kHz, 2 kHz and 4 kHz. The sampling method for this work was based on point sampling technique. This method applies to a set of number of points per unit area on the material's surface, whereas the probe was held in static in a given time to measure accurate intensity.

The sound intensity measurement was conducted from 16 to 32 points at the in front of the DPCWP surfaces. The measurement of sound power using sound intensity requires a normal component over a specific surface in front of the source [10] which can be described as

$$W = \int I_n dS \quad [2]$$

Where

$W$  = Sound Power of the source

$I_n$  = Normal component of intensity

$dS$  = Area measured on the material's surface

Considering the surface area as in Equation 2, the normal incidence sound absorption coefficient can be describes as follows

$$\alpha_n = \frac{I_n}{I_i} \quad [3]$$

Where

$I_n$  = Net sound intensity in front of the acoustic material

$I_i$  = Incident sound intensity when the acoustic material is removed

The size of the DPCWP of sound intensity measurement for this research work is 1.2 m x 1.2 m as it was proven that this dimension is decent enough to investigate the normal incidence sound absorption coefficient in front of the surface of the DPCWP [11]. It was placed in front of the sound source at 2 m distance in the anechoic chamber. All samples were investigated separately. Based on previous research findings, the sound intensity p-p probe should be positioned at  $\lambda/4$  to get minimum sound pressure level (SPL) [12]. However, for 4 kHz, the probe was positioned in front of the sample at  $5\lambda/4$  due to the equipment limitation. Table 1 shows the measurement distance for each frequency.

**Table 1** Measurement distance from the DPCWP surface

Frequency [Hz]	250	500	1000	2000	4000
Measurement Distance [m]	0.34	0.17	0.085	0.0425	0.08625

Figure 5 shows the sound intensity measurement work in the anechoic chamber, ACOLAB, Universiti Teknologi Malaysia. The volume of the anechoic chamber was 25.38 m<sup>2</sup> with a height of 2.17 m, length and width of 3.42 m. The sound intensity measurement was conducted by using a B&K 2260-E Investigator portable handheld system, B&K 3595 Sound Intensity Probe, and B&K Noise Generator type 4224.



**Figure 5** Sound intensity measurement process

It is also critical to define the measurement points before starting the sound intensity measurement. For accuracy, the points can be selected by focusing at

the middle of the DPCWP in equal number depending to the total area for each point. However the number of points can be decided upon the actual size of the DPCWP enclosing the source. There are also other options on how to decide total area and points for such DPCWP such as for any specific aperture location and shape depending to the pattern and style of the DPCWP. For example, the locations for the measurement points for DPCWP with floral design are shown in Figure 6. Later the measurement results were averaged to calculate the total sound absorption rate for the whole DPCWP surface.

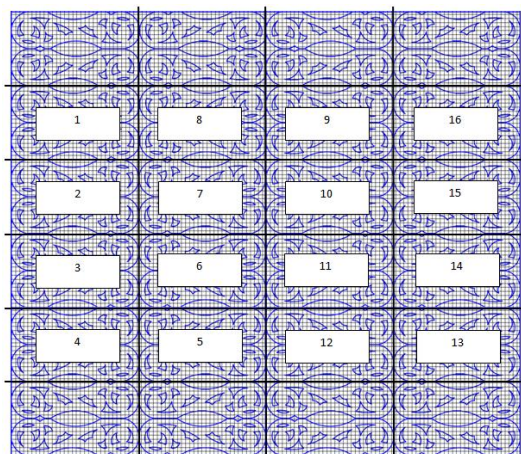


Figure 6 Measurement points for sound intensity method

## 2.2 Boundary Element Method

The simulation processes were started by identifying the coordinates of the quarter single pattern for every design and continued by creating 3 dimensional patterns, inserting meshing value, zone defining and boundary condition defining. A point source and internal points are created to simulate the net sound intensity values inside the anechoic chamber. Incidence sound intensity value was simulated by creating anechoic room without any panel. The normal incidence sound absorption coefficient ( $\alpha_n$ ) was gained by dividing net sound intensity value in front of the surface of the DPCWP with incident sound intensity obtained in an empty room. All measurements and coordinate used in BEASY Acoustic software were in meter (m). The advantage of the simulation process is, the patches can be repeated to draw a full dimension of DPCWP to match with experimental work. The thickness of the DPCWPs was set to 0.02 m. The acoustic impedance for all patches was set to be equal with acoustic impedance of the air with the volume of 1 m<sup>3</sup>. During the simulation, the reference pressure was  $2.0 \times 10^{-5}$  Pa. Other material properties including the air density was

set at  $1.21 \text{ kgm}^{-3}$  and the sound speed was set at  $340 \text{ ms}^{-1}$ .

The impedance for the patches of DPCWP and anechoic room were  $3.366 \times 10^6 \text{ kgm}^{-2}\text{s}^{-1}$  and  $415 \text{ kgm}^{-2}\text{s}^{-1}$ , respectively. The data for normal incidence sound absorption coefficient was calculated based on a number of internal points located in front of each aperture. The distance of internal points were 0.34 m, 0.17 m, 0.085 m, 0.0425 m and 0.08625 m for 250 Hz, 500 Hz, 1 kHz, 2 kHz and 4 kHz respectively. The strength of sound source was 0.0005 Pa/m. Figure 7 shows the simulation work using BEASY Acoustics software.

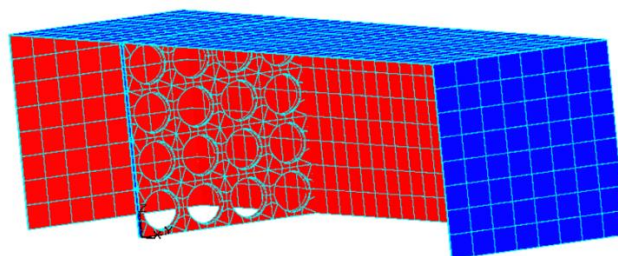


Figure 7 Simulation work using BEASY Acoustics software

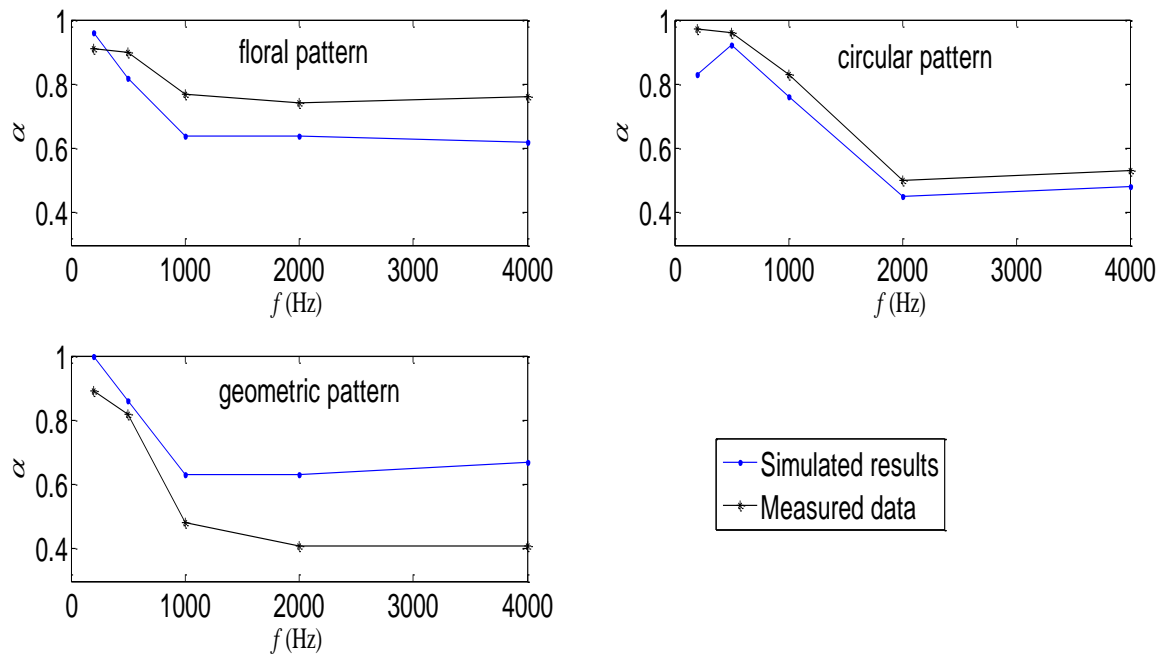
## 3.0 RESULTS AND DISCUSSION

For 30% and 40% perforation ratios, both simulation results for DPCWP with floral and geometric design have identical trend of  $\alpha_n$ , which is a smooth decline from low frequencies to 1 kHz, and towards higher frequency, the  $\alpha_n$  is almost a flat. For 30% and 40% perforation ratios, both simulation results for DPCWP with floral and geometric design have identical values of  $\alpha_n$ , as the tolerance for all frequencies is ranging from 0.01-0.08.

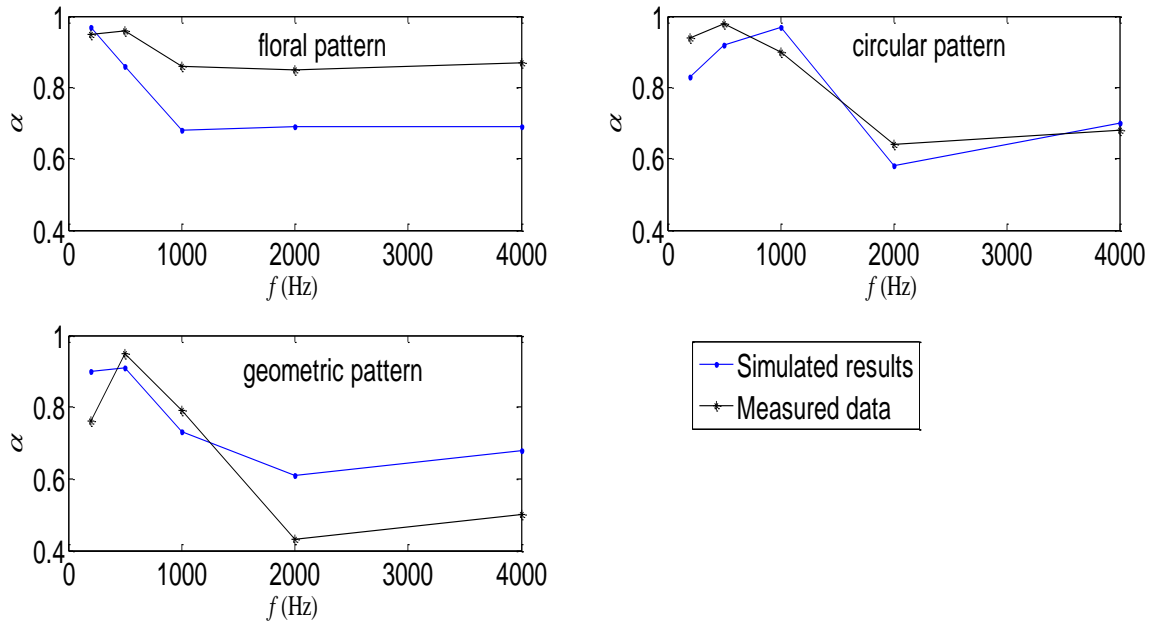
For 30% and 40% perforation ratios, DPCWP with the circular design has a small increase of  $\alpha_n$ , decreased as the frequency increased to 2 kHz, and at frequencies greater than 2 kHz, the  $\alpha_n$  value was almost flat. For this design, both perforation ratios show better  $\alpha_n$  at 1 kHz than DPCWP with floral and geometric design. For DPCWP with circular design, both simulation results and measurement results were identical to each other, which explain the simplicity of the shape of the design of the aperture can contribute to  $\alpha_n$  results. This is explained by Kuttruff, 2000 where the situation of sound pressure on a surface is identified with the relationship including the equivalent of mass area, the density of air and the perforation ratio. Which is in this case, the circular design has similar mass area and perforation ratio for each aperture. For DPCWP with floral and geometric design, the shape and design of every aperture were so complex. Even though the geometric design has uniform and symmetrical shape of the apertures, the combinations and locations of all repetitive apertures contribute to a complex design of DPCWP.

This is because there are a number of small dimension of apertures were included during the measurement process. The shape and design for each aperture for DPCWP with floral design was more complex compared to DPCWP with geometric design. The apertures have many curves and sharp edges, and arranged non-uniformly. However, there was no small aperture available for DPCWP with floral design compared to DPCWP with geometric design available for experimental and simulation processes. This is explained for both perforation ratios, DPCWP with floral design has better  $\alpha_n$  for almost from low

frequencies to high frequencies. Finally, the simulation and measurement results were identical for both perforation ratios for DPCWP with circular design. The simplicity of the design contributes to small tolerance for both results. However, DPCWP with a complex pattern, including floral and geometric design, have  $\alpha_n$  value range from 0.41 to 1 from low frequencies to high frequencies for both perforation ratios for simulation and measurement results. Figure 8 and Figure 9 show the  $\alpha_n$  results for all motifs for 30% and 40% perforation ratios respectively.



**Figure 8** Results comparison for floral, geometry and circular design for simulation and measurement method for 30% perforation ratio



**Figure 9** Results comparison for floral, geometry and circular design for simulation and measurement method for 40% perforation ratio

## 4.0 CONCLUSION

Based on the results, the DPCWP for all design with 30% and 40% perforation ratios can act as a good sound absorber material. This was demonstrated with the simulation and experimental results for all designs. The tolerance between simulation and experimental results was observed and this was because the different method to calculate the sound absorption coefficient. The results for measurement work are based on specific areas in front of the surface of the DPCWP, while simulation work results are based on individual internal points located for each aperture for all designs. Finally, the DPCWPs with 40% perforation ratio show better  $\alpha_n$  than 30% perforation ratio for both simulation and experimental results.

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