Investigating the Effect of Size and Shape of Perforations on Natural Frequency of an Acoustic Panel made of Natural Fiber Reinforced Composites by Modal Analysis

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Abstract. The main aim of this research is to analyse the modal response of an acoustic panel made of Natural Fiber Reinforced Composites (NFRC) by varying the size and shape of perforations in it. NFRC are proved to be excellent acoustic absorbers. Hence, researches have been made on developing an acoustic panel made of NFRC. Acoustic panels with perforations turned out to be successful because of its effective absorption. In general, researchers consider only the effect of size and shape of perforations on the acoustic absorption whereas, leaving away the effect of size and shape of perforations on the modal response. Hence this research has been performed to understand the effect of size and shape of the perforations on the modal response of an acoustic panel made of PLA-OPEFBF composite. Composite were prepared using conventional hot-press techniques. Design of an acoustic panel was made using SolidWorks and the modal response analysis is performed using ANSYS. The result shows increase or decrease in size of the perforation affects the natural frequency of the system. This research shows the importance of considering the effect of considering the size and shape of the perforations during the development of an acoustic panel.

Keywords: natural fiber reinforced composite, acoustic panel, size and shape of perforations, modal analysis.

INTRODUCTION

Acoustic panels are used in reducing the noise pollution by absorbing the sound from the environment and converting it into heat energy. Natural Fiber Reinforced Composites (NFRC) are becoming an integral part in developing an acoustic panel since, NFRC are bio-degradable, cost effective, low dense [1]. They also exhibit positivity in terms of acoustic absorption. However, researches have been in progress, to make the NFRC made acoustic panels absorb better in the lower frequency spectrums [2]. During this course of developing an acoustic panel, its outcome should not be limited only to its acoustic absorption; it should be concerned about the effect of vibrations as well. In both the cases, the material and the design of an acoustic panel matters.

Poly(lactic acid) is one of the thermoplastic polymers which is bio-degradable and non-toxic. PLA along with natural fibers as reinforcement has shown satisfactory results in terms of mechanical and acoustic properties [3]. Oil Palm in Malaysia is the second major agricultural crop after rubber. The industries which based on oil palm produces enormous amount of biomass [4]. Oil Palm Trunks (OPT), Oil Palm Fronds (OPF), Empty Fruit Bunches (EFB), Palm Pressed Fibers (PPF), Oil palm shells (OPS), Palm Oil Mill Effluent (POME) are the major biomass which are produced during palm oil production from palm oil industries [5]. EFB is the second most biomass which is left abundantly after the production of palm oil. Out of all fibrous biomass produced from oil palm tree, EFB alone produces nearly 75% of the fiber content [6].

Rahman et al., investigated the effect of fiber orientation on the natural frequency of the composite and concluded that, the flax- polypropylene composites can be commercialized for the applications in which vibration and noises are significant issues. Finite element analysis by ANSYS was used to predict the natural frequencies of the composite [7]. Perforations in the acoustical panel are also one of the important factors for its effective absorption. Liu et al., investigated the effect of perforations on acoustic absorption in an acoustical panel and concluded that, the diameter of the perforations and distance between the perforations affects the acoustic absorption [8]. However, acoustic panels with satisfactory absorption should have better natural frequency response as well.

Burgemeister and Hansen calculated the natural frequencies of the plate with macro perforations [9]. Ismail et al., studied the effect of micro holes on the natural frequency and mode of shape of the perforated plate made of aluminium [10]. Later, Ismail et al., investigated the effect on micro and macro perforations together on the natural frequency of the system They observed that, the perforations affect the natural frequency of the plate [11]. Nevertheless, the effect of perforations on the natural frequency of the natural fiber reinforced composites hasn't been explored. Therefore, this research investigates the effect of size and shape of the perforations on the natural frequency of an acoustic panel made of PLA-OPEFBF composite. PLA-OPEFBF composite was prepared by the conventional hot-press technique.

MATERIALS

Poly(lactic Acid) pellets are purchased from NatureWorks Corporation. Ingeo™ Biopolymer 2003D grade with the specific gravity of 1.24 was used. Oil Palm Empty Fruit Bunch fibers (OPEFBF) were obtained from the nearest palm oil mill. The average length of the fibers was ranging from 20 to 40 mm with the diameter ranging from 0.2 mm to 0.5 mm.

METHODS

Preparation of PLA-OPEFBF Composite

Fibers are soaked, rinsed and cleaned to get rid of impurities. Then, fibers are exposed to sunlight. PLA pellets along with the sun dried fibers were oven dried at 60 °C for 24 hours minimize the content of moisture [12]. Later, the dried fibers are grinded and sieved to less than 500 µm. 90 wt% PLA pellets along with the 10 wt% of OPEFBF were mixed and pre-heated at 180 °C for 5 minutes considering the melting temperature of pure PLA. Next, they were hot pressed with the load of 5 tons at 180 °C for 5 minutes followed by cold pressing for 5 minutes.

Mechanical Testing

Tensile testing was conducted using Instron Universal Testing Machine. Testing was conducted as per ASTM D638. Type V dog bone specimen with the overall length of 63.5 mm was considered as reference. 3 specimens were considered for testing. Figure 1 shows the Type V dog bone specimen considered for tensile testing.

FIGURE 1 Type V Dog Bone Specimen used for Tensile Testing

Modal Analysis

Modal analysis was performed using ANSYS 2019. Acoustic panel with the length of 40 cm, breadth of 20 cm and thickness of 3 cm was considered. Number of perforations was considered to 13*6=78. Back side of an acoustic panel is considered as fixed support since; acoustic panels will be fixed in walls of buildings. Two cases involving the different size and shape of the perforations were analysed. In the first case, the distances between the perforations are made as constants and the size of the perforations are varied for each of the geometry. Circle, square and rectangle are the geometries considered. In the second case, the distances between the perforations are varied by keeping the size of the perforations as constant. For both cases, its natural frequency response for each mode is analysed. 6 modes were selected for analysis. Figure 2 shows the detailed drawing of an acoustic panel with circular perforations; Figure 3 shows the detailed drawing of an acoustic panel with square perforations and Figure 4 shows the detailed drawing of an acoustic panel with rectangular perforations. All the design of an acoustic panel were made using SolidWorks.

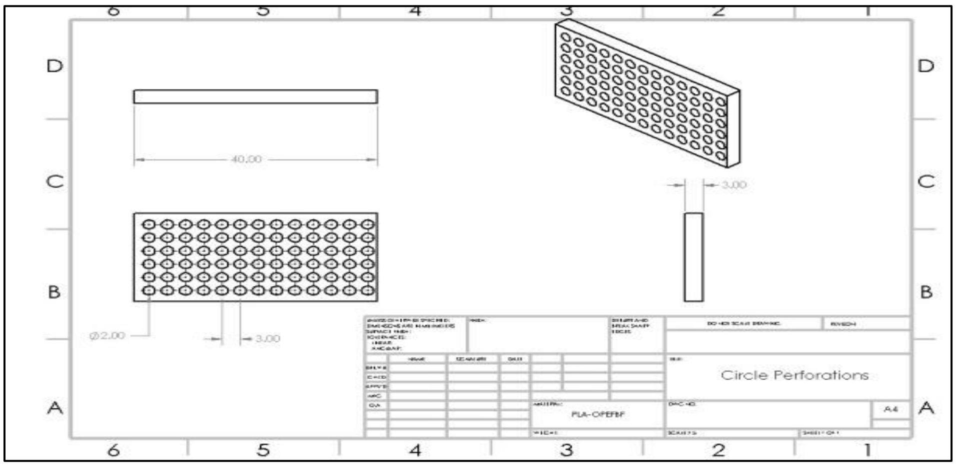

FIGURE 2 Detailed Drawing of an Acoustic Panel with Circular Perforations

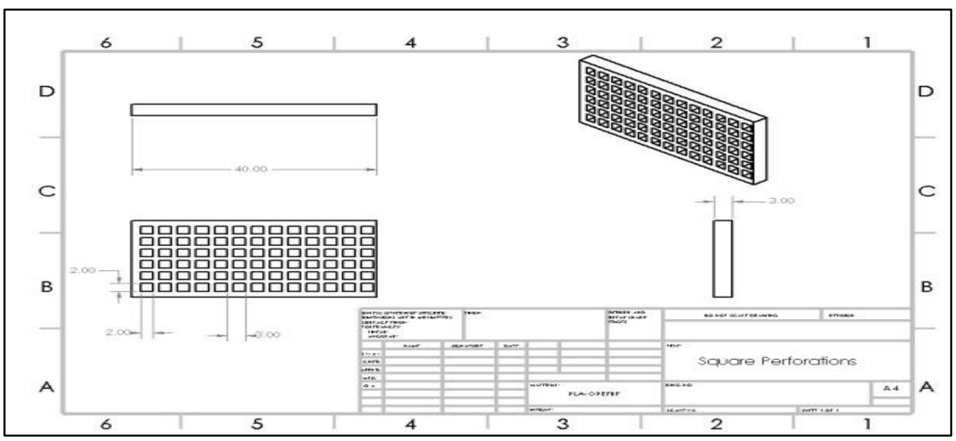

FIGURE 3 Detailed Drawing of an Acoustic Panel with Square Perforations

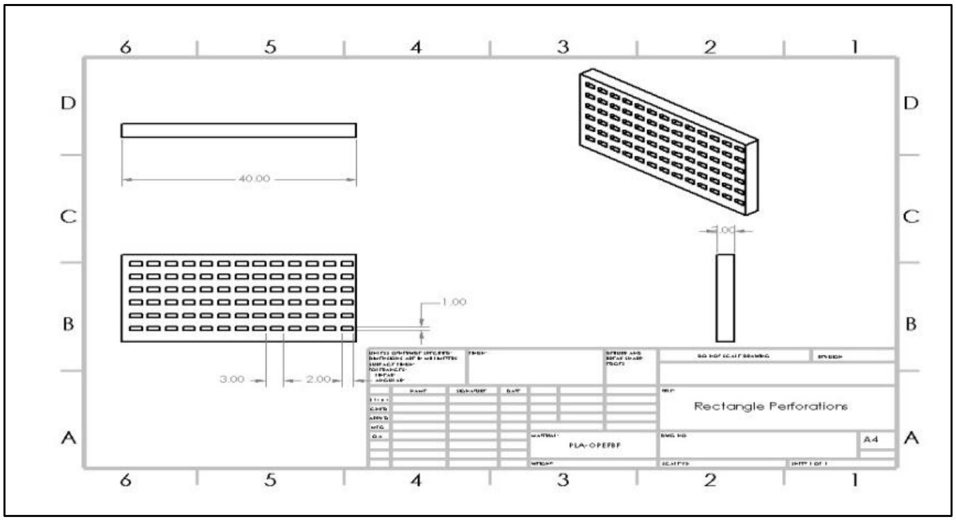

FIGURE 4 Detailed Drawing of an Acoustic Panel with Rectangular Perforations

Table 1 shows the case 1 with different geometry of perforations in an acoustic panel made of PLA-OPEFBF composite where 1a) considering circle perforations 1b) considering square perforations and 1c) considering rectangular perforations and Table 2 shows the case 2 with an acoustic panel with varied distance between the perforations.

TABLE 1a) Acoustic Panel with Circle Perforations

Geometry of Perforation	Distance between the Perforations in cm	Diameter of the Perforations in cm	Volume Excavated (Area * Thickness * No. of Perforations) in cm^3
Circle	3	0.5	183.69
	3	1	734.76
	3	1.5	1653.21
	3	2	2939.04

TABLE 1b) Acoustic Panel with Square Perforations

Geometry of Perforation	Distance between the Perforations in cm	Side of the Perforations in cm	Volume Excavated (Area * Thickness * No. of Perforations) in cm^3
Square	3	0.5	58.5
	3	1	234
	3	1.5	526.5
	3	2	936

TABLE 1c) Acoustic Panel with Rectangular Perforations

Geometry of Perforation	Distance between the Perforations in cm	Length of the rectangle in cm	Breadth of the rectangle in cm	Volume Excavated (Area * Thickness * No. of Perforations) in cm^3
	3	0.5	0.25	29.25
Rectangle	3	1	0.5	117
	3	1.5	0.75	263.25
	3	2	1	468

TABLE 2 Acoustic Panel with varied distance between the Perforations

Geometry of Perforation	Distance between the Perforations in cm	Diameter of the Perforations in cm	Volume Excavated (Area * Thickness * No. of Perforations) in cm^3
	2.75	0.5	183.69
Circle	3	0.5	183.69
	3.25	0.5	183.69

RESULTS AND DISCUSSION

Mechanical Properties of the composite

Table 3 shows the tensile properties of the tested specimen. There were formation of voids and non-uniform dispersion of fibers was noticed from the composite. Moreover, this non homogeneous distribution of fibers was considered as one of the main disadvantages in the compression molding [13].

TABLE 3 Tensile Properties of PLA-OPEFBF Composite

Specimen	Tensile Strength (MPa)	Tensile Modulus (MPa)
1	36.82	2525.60
2	32.86	2303.55
3	34.20	1652.54

Properties of the Specimen 1 were considered for ansys simulation since the other two specimens contains more voids. Dog bone specimen 1 was weighed, where its mass was found to be 1.099 g and based on the geometry of the dog bone specimen, its volume was calculated and found to be 1.54723 cm^3. From the above values, density (mass/volume) was calculated and found to be 0.7109 g/cm^3. Poisson ratio was calculated based on formula, negative ratio of the lateral strain to the longitudinal strain. The properties of the PLA-OPEFBF composites are calculated based on the results from tensile testing and are tabulated in Table 4.

TABLE 4 Properties of PLA-OPEFBF Composite

Material	Density (g/cm^3)	Poisson Ratio	Tensile Strength (MPa)	Tensile Modulus (MPa)
PLA-OPEFBF Composite	0.710	0.35	36.82	2525.6

Modal Response of an Acoustic Panel with Circle Perforations

Figure 5 shows the natural frequency at different modes for an acoustic panel with circular perforations with diameter of 0.5 cm. Modal response of an acoustic panel made of PLA-OPEFBF composite with circle perforations is analysed and the natural frequency values for first 6 modes are tabulated in Table 5.

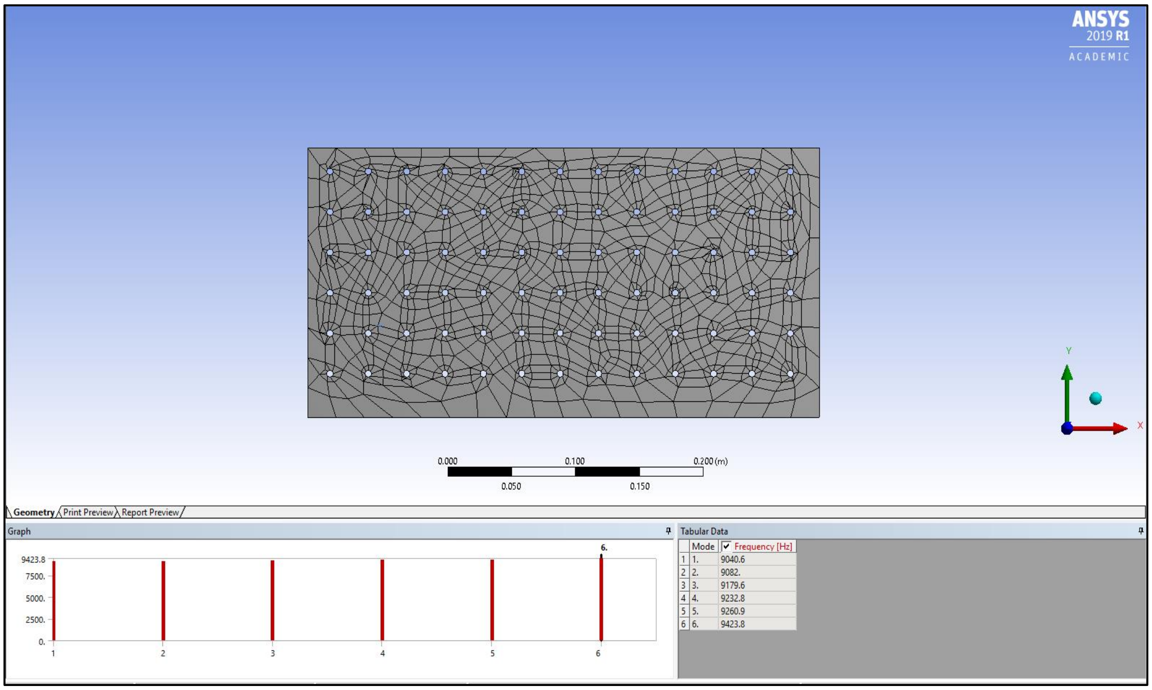

FIGURE 5 Natural Frequencies at Different Modes for an Acoustic Panel with Circular Perforations with Diameter of 0.5 cm

TABLE 5 Natural Frequency Values for First 6 Modes with Circle Perforations

Geometry of Perforation	Volume Excavated in cm^3	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)	Mode 4 (Hz)	Mode 5 (Hz)	Mode 6 (Hz)
Circle	183.69	9040.6	9082	9179.6	9232.8	9260.9	9423.8
	734.76	8868.1	8917.7	9006.7	9061.5	9080.8	9250.7
	1653.2	8590	8651	8742.4	8786.4	8811.1	8991.9
	2939.04	8179.7	8254.3	8380	8399.7	8445.3	8615.2

Figure 6 shows the trend between volume excavated in cm3 and natural frequency in Hz.

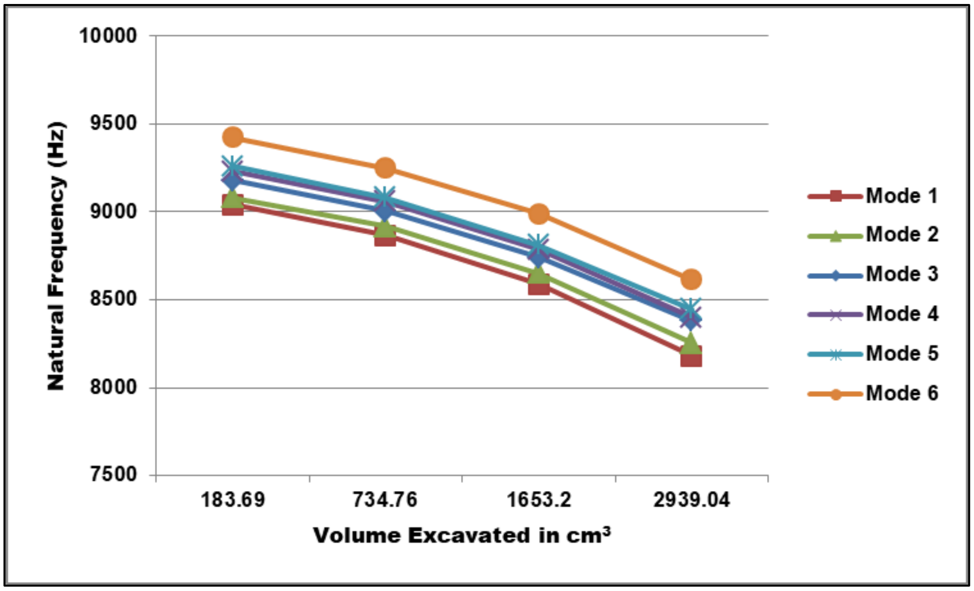

FIGURE 6 Trend between volume excavated in cm^3 and frequency in Hz.

It can be seen from the Figure 6, that the natural frequency at each mode tends to decrease when there is increase in excavation of volume. Excavation of volume is increased when size of perforation increases. Therefore, for an acoustic panel with perforations in circular geometry, its natural frequency decreases with increase in diameter of the perforations.

Modal Response of an Acoustic Panel with Square Perforations

Figure 7 shows the natural frequency at different modes for an acoustic panel with square perforations with side of 0.5 cm. Modal response of an acoustic panel made of PLA-OPEFBF composite with square perforations is analysed and the natural frequency values for first 6 modes are tabulated in Table 6.

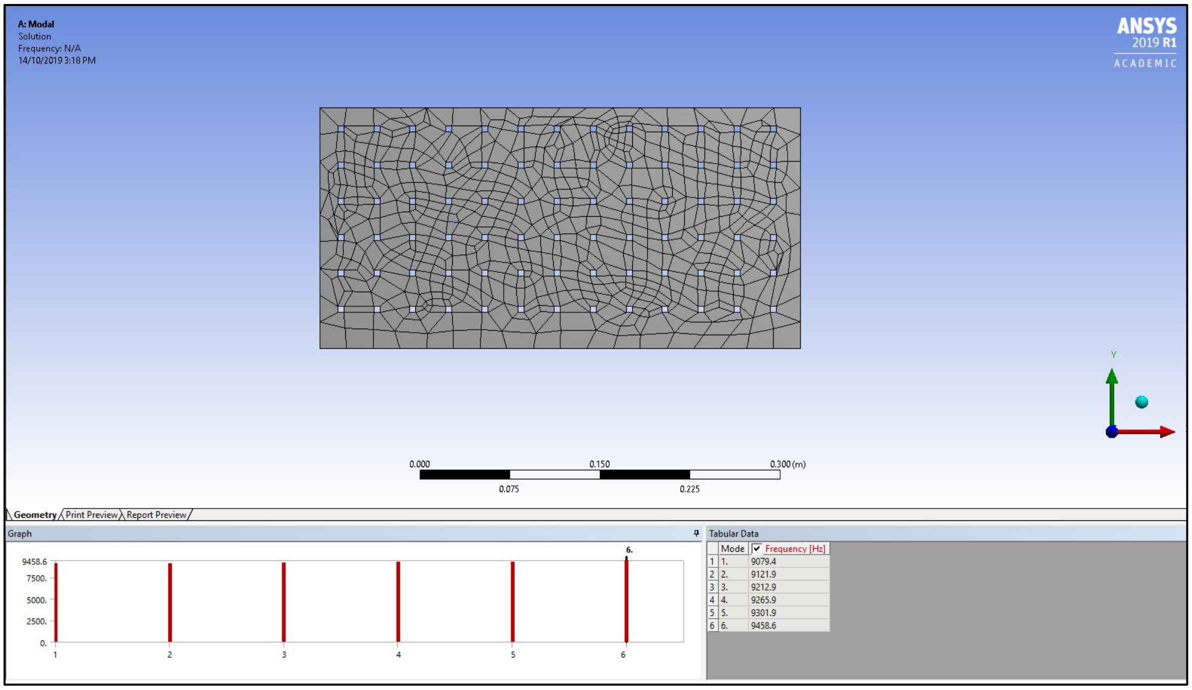

FIGURE 7 Natural Frequencies at Different Modes for an Acoustic Panel with Square Perforations with side of 0.5 cm

TABLE 6 Natural Frequency Values for First 6 Modes with Square Perforations

Geometry of Perforation	Volume Excavated in cm^3	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)	Mode 4 (Hz)	Mode 5 (Hz)	Mode 6 (Hz)
	58.5	9079.4	9121.9	9212.9	9265.9	9301.9	9458.6
Square	234	8870.2	8923.9	9011.3	9058.1	9091.1	9254
	526.5	8524	8585.3	8667.1	8708.3	8731.9	8909.3
	936	7850.2	7909.9	8016.8	8036.3	8098.6	8177.7

Figure 8 shows the trend between volume excavated in cm3 and natural frequency in Hz.

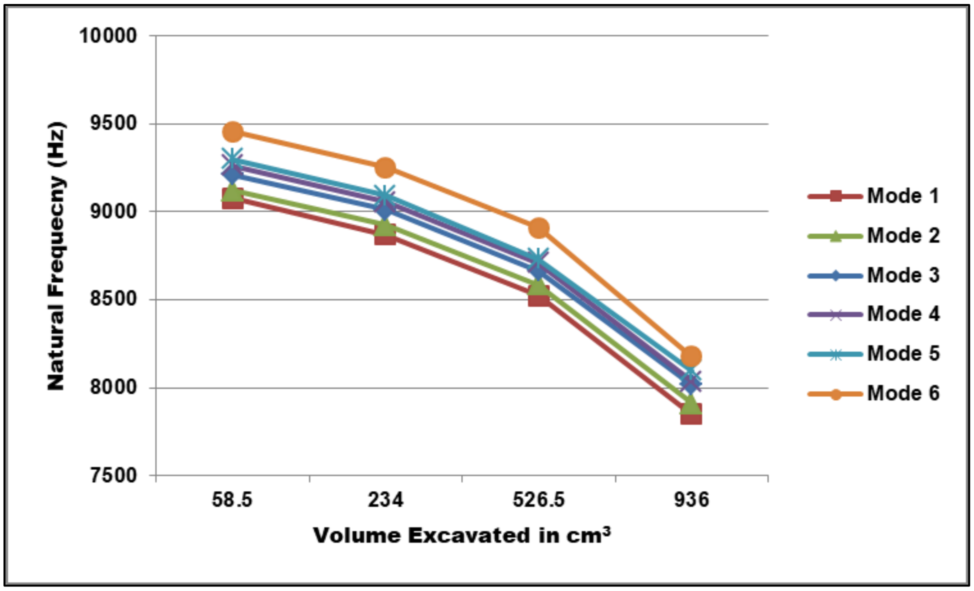

FIGURE 8 Trend between volume excavated in cm^3 and frequency in Hz.

It can be seen from the Figure 8, that the natural frequency at each mode tends to decrease when there is increase in excavation of volume. Excavation of volume is increased when size of perforation increases. Therefore, for an acoustic panel with perforation in square geometry, its natural frequency decreases with increase in side of the perforations.

Modal Response of an Acoustic Panel with Rectangular Perforations

Figure 9 shows the natural frequency at different modes for an acoustic panel with rectangular perforations with length of 0.5 cm and breadth of 0.25 cm. Modal response of an acoustic panel made of PLA-OPEFBF composite with square perforations is analysed and the natural frequency values for first 6 modes are tabulated in Table 7.

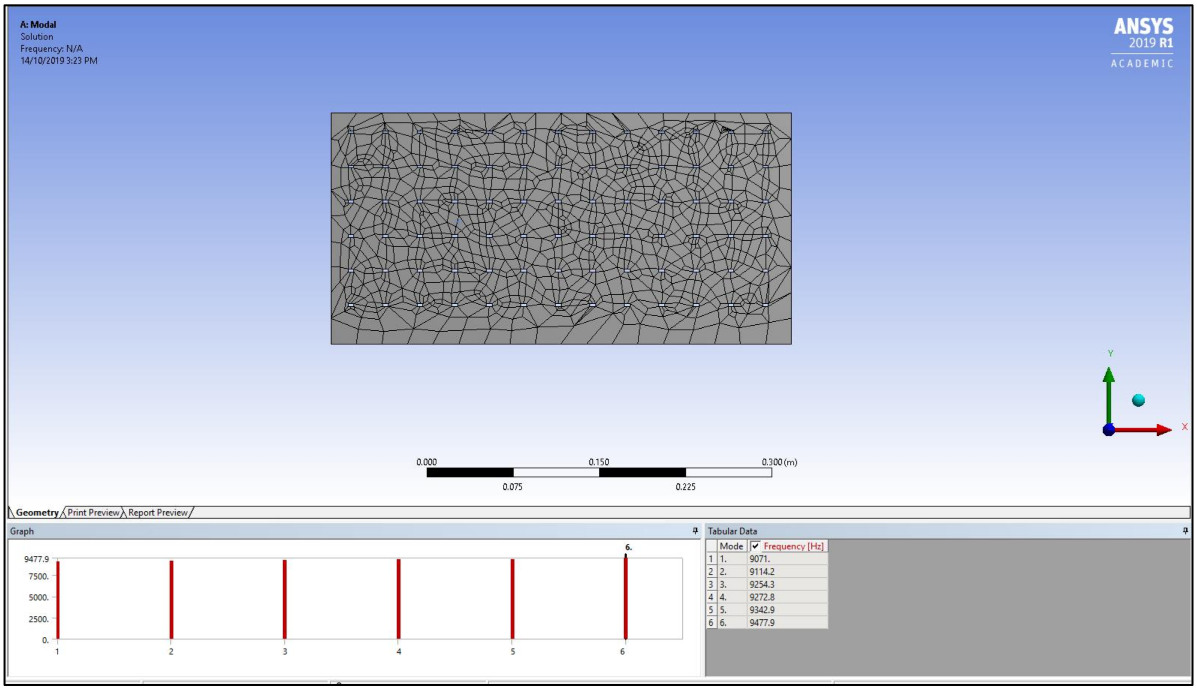

FIGURE 9 Natural Frequencies at Different Modes for an Acoustic Panel with Rectangular Perforations with Length of 0.5 cm and Breadth of 0.25 cm.

TABLE 7 Natural Frequency Values for First 6 Modes with Rectangular Perforations

Geometry of Perforation	Volume Excavated in cm^3	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)	Mode 4 (Hz)	Mode 5 (Hz)	Mode 6 (Hz)
	29.25	9071	9114.2	9254.3	9272.8	9342.9	9477.9
Rectangle	117	8859.1	8921.7	9094.5	9188.3	9248.4	9345.9
	263.25	8571.1	8646.5	8827.4	9027.4	9041.8	9113.5
	468	8071.7	8156.6	8318.5	8476.4	8542.0	8579.8

Figure 10 shows the trend between volume excavated in cm^3 and natural frequency in Hz.

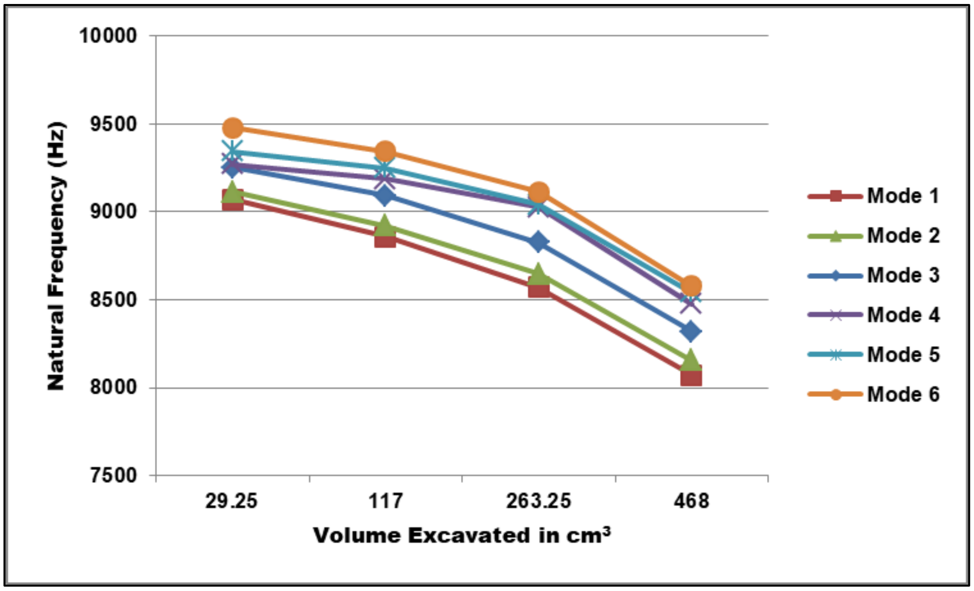

FIGURE 10 Trend between volume excavated in cm^3 and frequency in Hz.

It can be seen from the Figure 10, that the natural frequency at each mode tends to decrease when there is increase in excavation of volume. Excavation of volume is increased when size of perforation increases. Therefore, for an acoustic panel with perforations in rectangular geometry, its natural frequency decreases with increase in length and breadth of the perforations.

In an overall basis, it can be seen that, there is a decrease in natural frequency of an acoustic panel made of PLA-OPEFBF composite with increase in size of perforations for each of the geometry. This is because; certain volume of material is getting excavated when the size of perforation increase. Excavation of material obviously disturbs the stiffness of the material which in turn affects the natural frequency of the system since; natural frequency of the system is proportional to the stiffness of the material. Similar trend was seen when moderate and micro perforations are made in the plate made of different material [9].

Modal Response of an Acoustic Panel with varied distance between the Perforations

Figure 11 shows the natural frequency at different modes for an acoustic panel with circular perforations with diameter of 0.5 cm and distance between the perforations was 2.75 cm. Modal response of an acoustic panel made of PLA-OPEFBF composite with circular perforations is analysed and the natural frequency values for first 6 modes are tabulated in Table 8.

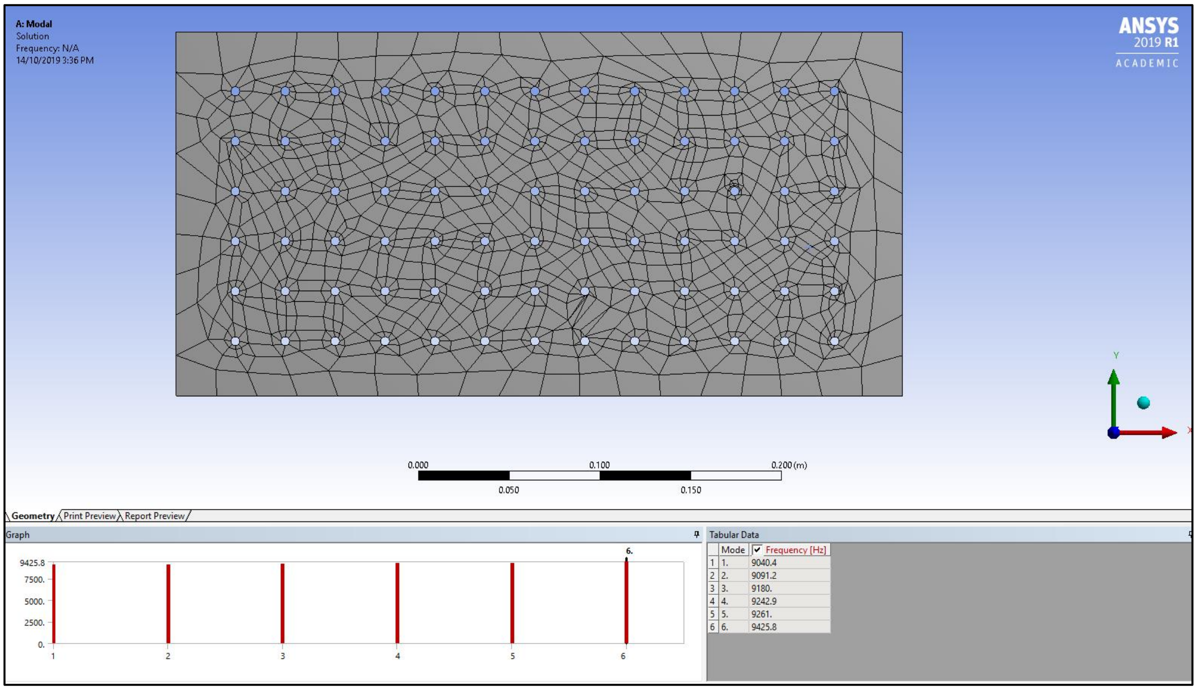

FIGURE 11 Natural Frequencies at Different Modes for an Acoustic Panel with Circular Perforations with Diameter of 0.5 cm and distance between the Perforations as 2.75 cm.

TABLE 8 Natural Frequency Values for First 6 Modes with Circle Perforations

Geometry of Perforation	Distance between the Perforations in cm	Volume Excavated in cm^3	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)	Mode 4 (Hz)	Mode 5 (Hz)	Mode 6 (Hz)
Circle	2.75	183.69	9040.4	9091.2	9180	9242.9	9261	9425.8
	3	183.69	9040.6	9082	9179.6	9232.8	9260.9	9423.8
	3.25	183.69	9040.7	9074.3	9193	9227.4	9276.2	9429.3

It can be seen from the Table 8 that there is no significant changes in natural frequency of an acoustic panel made of PLA-OPEFBF composite. This is because; by increasing or decreasing the distance between the pores, is not going to alter the excavation of material from the object. This means excavation volume remains constant. Hence, natural frequency of an acoustic panel made of PLA-OPEFBF doesn't vary much when the distance between the perforations is varied, provided the number of perforation is kept as constant. However, slight variations in the natural frequency can be seen because; when the distance between the perforations are increased or decreased, the position of perforations gets altered. This needs further investigation with major positive and negative values of distance between the perforations.

CONCLUSION

PLA-OPEFBF composite was successfully produced by hot press technique and the properties of the composite were evaluated. The design of an acoustic panel was made by SolidWorks. Modal analysis was performed on an acoustic panel considering PLA-OPEFBF as a material using ANSYS. It was seen that the increased size of perforations for each of the geometry decreases the natural frequency of the system. In case of, increase or decrease in distance between the perforations, natural frequency of the system doesn't significantly get affected, provided with constant number of holes. However, experimental validation should be carried out to ensure the material properties are accurate which will be performed in the upcoming studies. From this research it is clear that, the researcher who are about to develop an acoustic panel should optimize the size and shape of perforations considering the modal response in addition with the acoustic absorption. By this, researchers can develop an acoustic panel with optimum acoustic absorption and modal response.

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