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Original Paper

[ICACE2019] Experimental free vibration analyses of scaled open-hole epoxy copper composite structures

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Abstract: There are different causes for failure and cracks in composite materials, such as vibrations. The behavior of a composite structure is based on its mechanical and physical properties. Modern composite materials are usually optimized to get special mechanical properties used in different applications, such as airplanes. In the present study, we investigated the free vibration behavior of copper composite plates with holes. The damping ratio and natural frequency for different samples manufactured from fiber and copper were analyzed. The holes on the sample plate were of different diameters (2, 4, 6, 8, 10, and 12 mm), and the width to diameter ratio was fixed at 6. Vibration modal analysis tests were conducted to evaluate the effect of hole size. The results showed that the natural frequency increased with an increase of the hole size in the low frequency mode under 300 Hz; however, frequency was not related to hole size over 500 Hz. Damping ratio was found to be affected by the hole size; the appropriate hole size was 2 mm in the low frequency mode and 8 mm in the high frequency mode in order to get high damping ratio.

Keywords: Free vibration, Hole size, Composite plate

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1. Introduction

A composite material is a material made of two or more constituent materials having different chemical or physical properties. A combination of these materials gives features different from those of individual materials **[1]**. Vibration can occur in the moving part. When a composite material is applied to vibration parts, a failure can occur if the amplitude is above a certain limit. When composite materials are used in the production of important aircraft components, such as wings, helicopter blades, and helicopter rotors, the fatigue problem must be considered due to high vibration of those parts **[2]**. Vibration analysis is used to measure the level of vibration and frequencies of the machinery used in various industries **[3]**. The operation mode of an accelerometer is given by the voltage level that is directly proportional to the vibration level **[4]**. A study that experimentally investigated different vibrated rotating cantilever beams, such as turbo engines blades, helicopter blades, and wind turbine blades, showed that the difference hole shapes have different effects on the composite structure failure **[5]**. To determine the free vibrations of beams and plates, another study analyzed natural frequency **[6]**.

Furthermore, many studies investigated the free vibration of materials. When amplitude is high during vibration, the material is under some danger, and this high amplitude must be checked for the material to last for a longer period of time **[7]**. Vibration analysis is used to detect high amplitude of composite materials. For instance, several studies experimentally investigated the effect of hole shape on vibration **[8][9]**. Other studies analyzed hole size and fiber thickness **[10][11]**. Furthermore, in order to understand the effect of natural frequency of the composite laminate material, several studies tested the location of holes **[12][13]**. In previous studies on different thickness values of laminate materials with different loadings, three types of in-plane loading were studied as variables **[14]**. The fatigue test for the samples made from the glass or fiber with copper epoxy composite under different loadings was performed by **[15]**. Fatigue life was modelled with the residual stiffness and strength. The model of fatigue was also studied **[16]**.

Modal analysis process is a way to describe a structure taking into account its natural features such as frequency, damping,

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and the mode of shapes **[11][17]-[19]**.

The main aim of the present study was to investigate vibration characteristics of copper composites plates with scaled open holes. Six specimens were prepared on the vibration test rig. The vibration input was given by four different modes, ranging from low frequency to high frequency. Natural frequency and damping ratio were analyzed using hole size variation.

2. Experimental Setup

Holes with different size were prepared on the composite plate; then the plate was subjected to different modes of vibration generated by special excitation force. In the next step, vibration parameters were measured. The overall length of the plate was 100 mm, and the width was decided by the hole diameter. The ratio of width to diameter was fixed at 6. This ratio was proposed by **[20]**.

The components and instrumentation of the experiment test rig are shown in **Figure 1**. The test rig was composed of vibration structure, impact hammer, data collection box, and LDS power amplifier. The impact hammer was used to prepare the vibration excitation force for each mode. The hammer load was adjusted by an accelerometer. The data were transferred to a data acquisition system for further analysis.

The holes were prepared in the middle of the sample plate as shown in **Figure 2**. The six hole sizes of 2, 4, 6, 8, 10, and 12 mm were selected, and the thickness of composite was fixed at 1.5 mm.

Figure 3 shows the four test modes prepared by the electronic hammer. Mode 1 had the lowest frequency, while Mode 4 had the highest frequency. The different modes were based on the shape of external excited force affected on the samples.

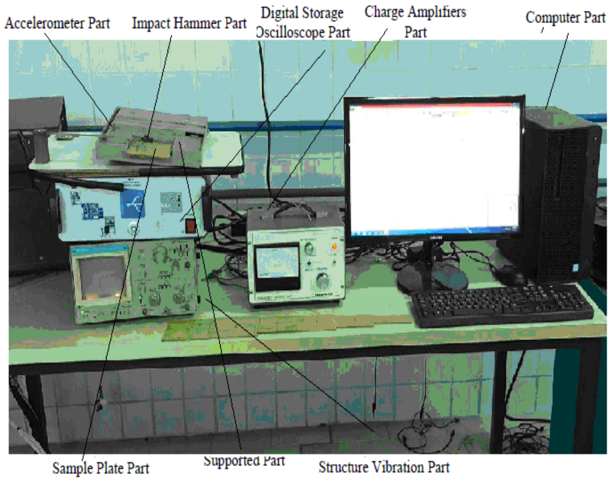

Figure 1: Experimental setup

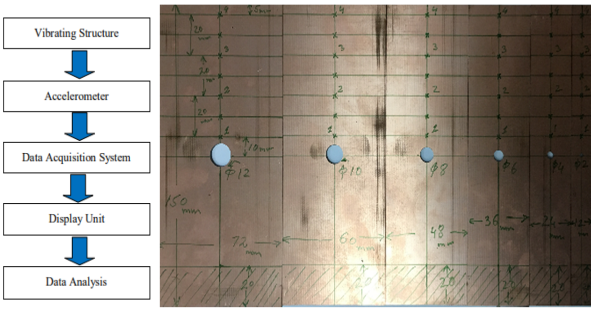

Figure 2: Analyzing process and photos of test sample

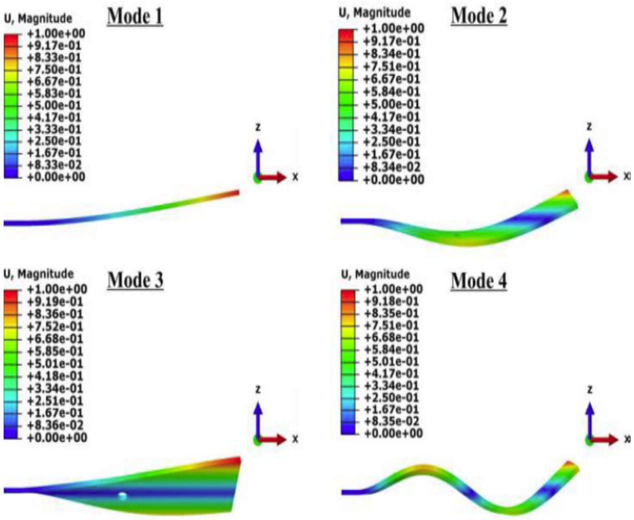

Figure 3: Test modes

3. Results and discussion

Figure 4 and **Figure 5** show natural frequency variation and damping ratio with the hole size variation in Mode 1. Natural frequency ranged from 22 Hz to 25 Hz in hole diameter of 2 mm, 30 Hz in the diameter of 4 mm, and 40 Hz in the case of 12 mm. With an increase of hole size, natural frequency increased. Frequency was two times higher in hole diameter of 12 mm than in the case when the diameter was 2 mm. Damping ratio variation was not proportional to hole size. Damping ratio was high in the cases of 2 mm, 4 mm, and 12 mm, and low in the cases of 6 mm, 8 mm, and 10 mm. Therefore, in order to increase damping ratio in the case of low frequency mode, hole size must be smaller than 4 mm or lager than 12 mm.

Figure 6 and **Figure 7** show natural frequency variation and damping ratio with hole size variation in Mode 2. As in Mode 1, natural frequency variation in the case of Mode 2 increased with an increase of hole size. Natural frequency in the hole diameter of 2 mm was 210 Hz, and increased until 270 Hz in the diameter of 12 mm. Damping ratio was high in the cases of 2 mm and 6 mm, and low in the cases of 4 mm, 8 mm, 10 mm, and 12 mm.

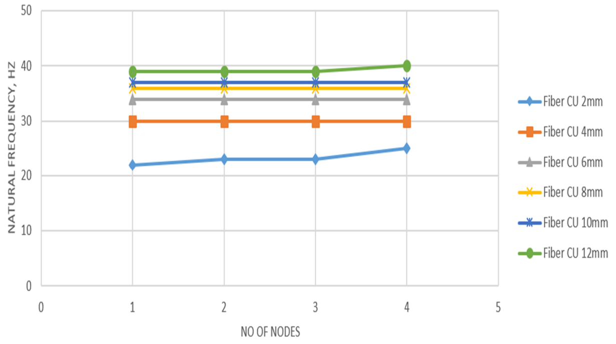

Figure 4: Natural frequency variation in Mode 1

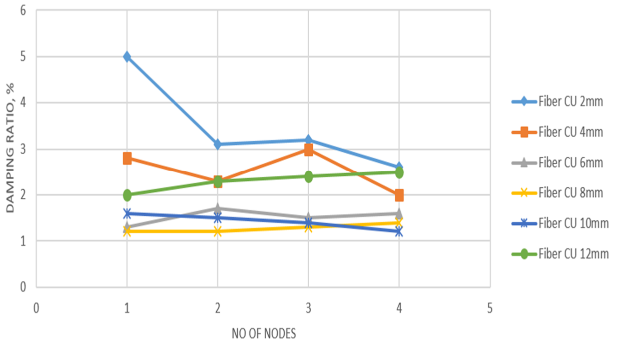

Figure 5: Damping ratio variation in Mode 1

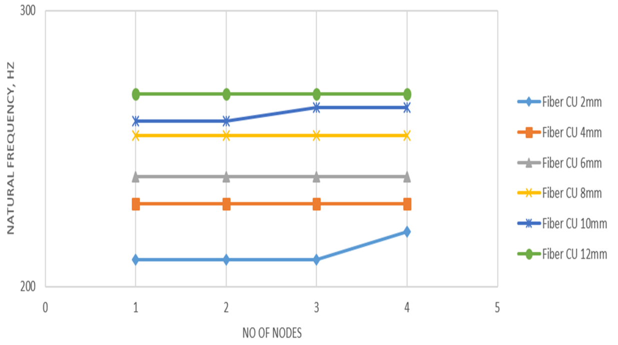

Figure 6: Natural frequency variation in mode 2

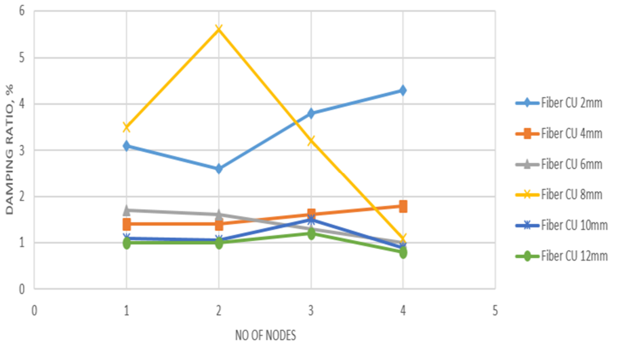

Figure 7: Damping ratio variation in Mode 2

In the case of Mode 3, natural frequency variation was different from that in Modes 1 and 2 (**Figure 8**). Natural frequency was the highest in the hole diameter of 8 mm and the lowest in the case of 4 mm. Other diameters of 2, 6, 10, and 12 mm had a medium range of frequency (about 670 Hz). **Figure 9** shows damping ratio variation with hole diameter variation in Mode 3. Damping ratio remained in high in the hole size from 2 to 8 mm, while the ratio was low in the hole size over 10 mm.

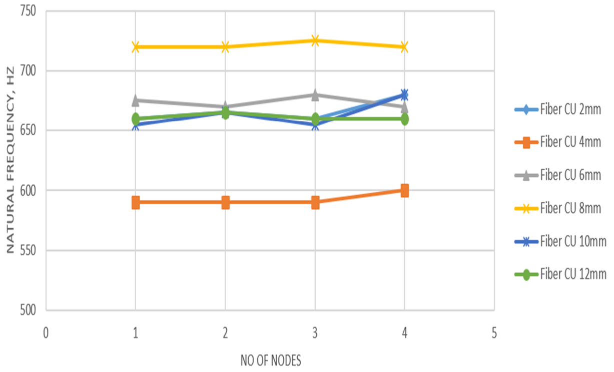

Figure 8: Natural frequency variation in Mode 3

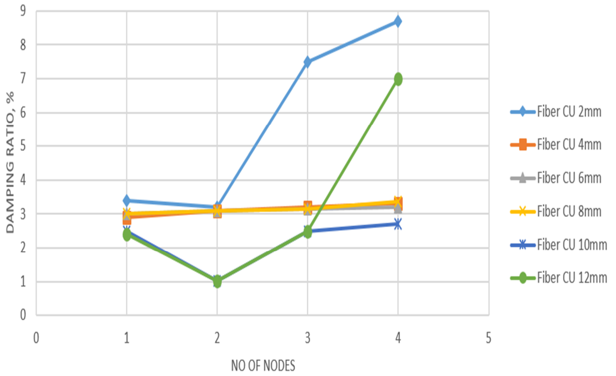

Figure 9: Damping ratio variation in Mode 3

Figure 10 and **Figure 11** show natural frequency variation and damping ratio with hole size variation in Mode 4 that had the highest frequency. Natural frequency was the highest in the hole diameter of 6 mm, and mixed up from 1130 Hz to 1190 Hz in the hole size from 2 mm to 10 mm. In the case of 12 mm, natural frequency considerably reduced to 1040 Hz. The damping ratio level was divided into two groups. The ratio was high in the hole diameter from 6 mm to 10 mm, and low in the diameter of 2 mm, 4 mm, and 12 mm.

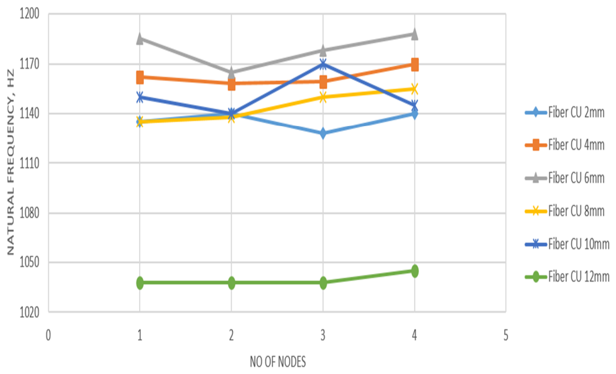

Figure 10: Natural frequency variation in Mode 4

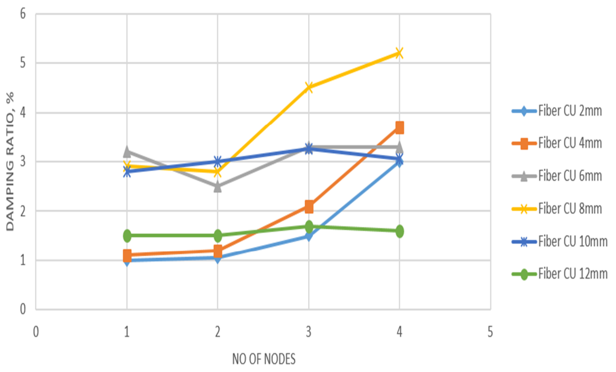

Figure 11: Damping ratio variation in Mode 4

4. Conclusion

In the present study, we investigated vibration characteristics of a composite plate with open scaled holes. The experimental results can be summarized as follows.

In the low frequency mode under 300 Hz, natural frequency increased with an increase of hole size, while damping ratio variation was not proportional to hole size variation.

In the high-frequency mode over 500 Hz, natural frequency and damping ratio variation were not proportional to hole size variation anymore. In Mode 3, natural frequency was the highest in the hole diameter of 8 mm and the lowest in the case of 4 mm, while damping ratio remained high in the hole size from 2 to 8 mm. In Mode 4, natural frequency was the highest in the hole diameter of 6 mm, and considerably lower (1040 Hz) in the case of 12 mm. Damping ratio was high in the hole diameter from 6 mm to 10 mm. Damping ratio was found to be affected by hole size. The appropriate hole size was 2 mm in the low-frequency mode and 8 mm in the high-frequency mode in order to get a high damping ratio.

Author Contributions

Conceptualization, F. Aldaihani, K. H. Park; Methodology, F. Aldaihani; Software, F. Aldaihani; Validation, F. Aldaihani, K. H. Park; Formal Analysis, F. Aldaihani; Investigation, F. Aldaihani; Resources, F. Aldaihani; Data Curation, F. Aldaihani; Writing—Original Draft Preparation, F. Aldaihani; Writing—Review & Editing, K. H. Park; Visualization, F. Aldaihani; Supervision, K. H. Park; Project Administration, K. H. Park.

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