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# Investigation of Vibration Characteristics of Stir Cast Aluminum Reinforced SiC Composite Beam

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**ABSTRACT**

In various applications such as plant mines or mechanical systems, machines in operation generate significant vibrations which are transmitted from the foundation to the surrounding environment and precision instruments. In order to minimize these vibrations, they must be either isolated, absorbed, or damped. The current study investigates the effects of an oil damper, passive vibration isolator, and absorbers (single and double) on the vibration frequency of a composite beam made of Al6061 (with 90% weight fraction) and SiC (with 10% weight fraction) produced through the stir casting process. Experimental analysis was conducted on the fabricated composite beam to investigate the frequencies of the fundamental vibration modes under hinged-hinged, fixed-free, and fixed-hinged boundary conditions. Results indicate that the absorber, damper, and isolator have a significant effect in reducing the amplitude of vibrations, resulting in lower frequencies compared to the main frequency. Furthermore, as the number of holes in the beam increases, the frequencies decrease due to a decrease in stiffness. The frequencies are higher for fixed-free end conditions without holes compared to other conditions. The oil damper was found to be more effective in reducing vibrations compared to absorbers and isolators.

## 1. INTRODUCTION

Aluminum metal matrix composites are advanced materials that possess several beneficial properties, such as high stiffness, high specific strength, high hardness and wear resistance, high thermal conductivity, increased component lifetime, high energy absorption and damping capacity, low coefficients of thermal expansion and friction, and the ability to withstand high stresses. These properties make them suitable for use in various industries, including automobiles, aerospace and aircraft, sports goods, offshore and marine industries, and more.

When a dynamic system is subjected to steady-state harmonic excitation, it vibrates with the excitation frequency. The sine-sweep method, which involves changing the frequency from initial to final values with a given time-rate (ramp), constant frequency, and variable frequency methods, can be used to give harmonic excitation. Under the resonance condition, the excitation frequency matches one of the natural frequencies of the system, causing dangerously large oscillations that can lead to structural failure, such as in bridges, buildings, or airplane wings. Therefore, determining the frequencies is crucial in studying vibrations.

A recent study examined the vibration characteristics of Al6061-SiC and Al6061-Al2O3 metal matrix composites for internal combustion mountings [1]. The study concluded that both types of composites provide superior stiffness and damping compared to steel. Similarly, the study [2] investigated metal matrix composites with aluminum as the base material and silicon carbide particles as reinforcement, studying the influence of the percentage of silicon carbide and fly ash. The natural frequency of the cantilever beam was found to increase with an increase in silicon carbide incorporation. Another study [3] analyzed the natural frequency of an aluminum / graphite metal matrix composite both analytically and experimentally. Additionally, the study [4] investigated the natural frequency and damping ratio of an aluminum metal matrix sandwich composite with the addition of silicon carbide particles, where the core was made using magnetorheological fluid. The study found that the composite with MR fluid exhibited exceptional vibration suppression ability. Lastly, the study [5] examined the effect of magneto rheological (MR) fluid and the vibration suppression capacity of glass fiber reinforced polyester composite.

In an effort to improve the structural rigidity of elastomers, fiber reinforcement has been proposed as a potential replacement for steel [6]. This investigation compared the vertical compression modulus of a square fiber-reinforced elastomeric bearing to that of an equivalent steel-reinforced elastomeric bearing for the purpose of vibration isolation.

Results showed that fiber reinforcement significantly reduced the vertical frequency of a vibration isolation system compared to a steel-reinforced bearing of the same design, indicating potential value for these applications. The effect of delamination and stacking sequence on the vibrational properties of graphite-epoxy composite was investigated by another researcher [7]. To introduce compressive stress, the composite shell was pre-twisted. A study by researcher [8] involved fabricating the Al2O24/B4C particulate composite with varying weight percentages of B4C in the stir casting process. The influence of the weight percentage of B4C on the tensile behaviour was examined, and it was concluded that the ultimate tensile strength and yield strength increased with the increase of the weight percentage of B4C while the percentage of elongation decreased. Additionally, researcher [9] investigated the influence of TiB2, with a weight percentage of 5% in Al356.1, on the tensile strength and hardness at different temperatures.

In a study, researchers [10] explored the impact of weight fractions of SiC ranging from 2.5%-10% in 2.5% and 5% fly-ash reinforced Aluminium 6061 on tensile strength, harness, and impact strength. They found that as the weight fraction of SiC particles increased, so did the tensile strength, hardness, and impact strength. Another study [11] examined the mechanical properties of Al6063/SiC composites by varying the size of SiC particles and weight percentages. They discovered that increasing the particle size and weight percentage of SiC improved hardness, tensile strength, and yield strength, but led to decreased impact strength and ductility.

Authors [12] investigated the wear and mechanical properties of Al7075/B4C composites, which were fabricated using Friction Stir casting. Meanwhile, researchers [13] developed Al alloy metal matrix composites with fused zirconia alumina and conducted experiments to examine the mechanical properties, such as tensile strength, hardness, and impact strength. They found that the optimal mechanical properties were achieved with a composition of 90% Al and 10% zirconia by weight percentage. The effect of fly ash and zircon as reinforcement in Al7075 was examined in another study [14], which investigated mechanical properties such as wear rate, tensile strength, and hardness. The findings revealed that fly ash reduced wear rate and increased tensile strength and hardness.

Authors [15, 16] prepared the composite Al6063/$Al_2O_3$ with zircon sand and evaluated the mechanical properties, concluding that a combination of 4wt% $ZrSiO_4$ and 4wt% $Al_2O_3$ yielded higher values of hardness and tensile strength. Meanwhile, another study [17] investigated the hardness and wear properties of the Al356.1/$ZrO_2$ nanocomposite fabricated with different weight fractions of $ZrO_2$ nanoparticles, finding that increased weight fraction of $ZrO_2$ particles improved wear properties.

In their investigation, author [18] analysed the mechanical properties, including tensile strength, compressive strength, hardness, and ductility, of a composite fabricated with Al6061 and fly ash. Their findings indicated that increasing the fly ash particle size leads to a decrease in mechanical properties and an increase in compressive strength, ultimate tensile strength, and hardness with the increase of weight fraction of fly ash. However, the hardness properties decrease with the increase of fly ash particle size. Another study [19] investigated the effect of fly ash reinforced with Al6061 on the mechanical properties and observed that an increase in fly ash composition increases the mechanical properties.

Various hard particles such as titanium carbide [20], aluminum oxide [21], silicon carbon [22], carbon nanotubes [23], and graphene [24] have been incorporated into metal matrix composites. The literature indicates that most authors have investigated the mechanical and tribological properties, while only a few authors have investigated the frequencies on fabricated specimens made of different reinforcement materials. Silicon carbide particles stand out due to their ability to suppress vibration, as well as their cheapness and easy availability. The present study aims to investigate the effect of oil damper, absorber, passive isolator, and the number of holes on the frequency and amplitude of vibration of Al6061/SiC beam, which could have potential applications in various industries, particularly those that require high levels of durability and structural stability.

## 2. EXPERIMENTAL DETAILS

The composite sample was fabricated using the stir casting technique, where aluminum 6061 was used as the base material and silicon carbide was used as the reinforcement. To achieve a homogenous mixture, SiC in powder form was added to molten aluminum 6061 and stirred using a mechanical stirrer. The rectangular cross-section composite beam was fabricated with 10 wt.% of silicon carbide and had dimensions of 730mm length, 40mm width, and 8mm thickness. Several holes were drilled along the length of the beam with a diameter of φ10mm to analyse their effect on vibration characteristics.

(a) Specimen without holes

(b) Specimen with holes

**Figure 1.** Specimen details


**Figure 2.** Vibration fundamental trainer

To investigate the effect of the number of holes and passive isolator, damper, and absorber on the frequency, various tests were carried out on the Al6061/SiC beam under hinged-hinged, fixed-free, and fixed-hinged boundary conditions using a vibration fundamental trainer. Figure 1 depicts the specimen with and without holes, while Figure 2 displays the experimental setup used for conducting the experiments.

The weight of the specimen with the number of holes is presented in grams in Table 1.

**Table 1.** Weight of composite beams in *g*

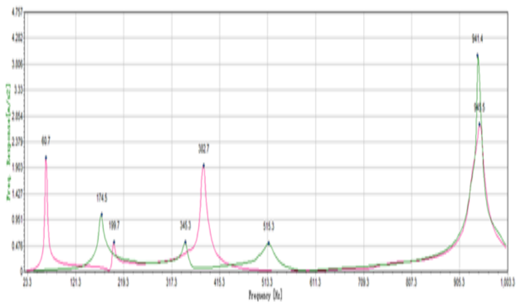
| Number of Holes | Weight (*g*) |
|---|---|
| Without holes | 640 |
| With 2 holes | 630 |
| With 4 holes | 620 |

## 3. RESULTS AND DISCUSSION

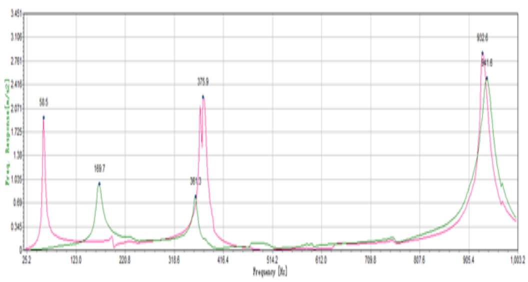
In order to investigate the forced vibration behavior of the Al6061/SiC beam, a series of experiments were carried out. The study focused on analyzing the impact of the oil damper, single absorber, double absorber, and passive isolator on the frequency. A detailed account of the findings is presented in the following sections.

### 3.1 Effect of oil damper

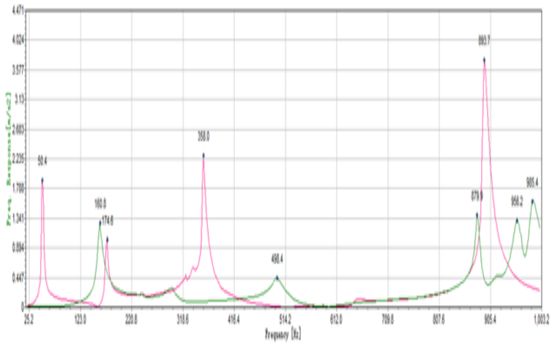
Figures 3-5 depict frequency response plots that illustrate the relationship between the output (acceleration) and input signal frequency for the beam. The peak values in the frequency response function plots correspond to the natural frequencies of the beam under various boundary conditions. The pink curve represents the frequency response of the beam without an oil damper, while the green curve represents the frequency response of the beam with an oil damper. Analysis of Figures 3-5 reveals that, regardless of the boundary conditions and the number of holes, the oil damper has absorbed the first natural vibration frequency. Furthermore, the natural vibration frequency decreases with an increase in the number of holes on the beam for the Hinged-hinged and Fixed and Free boundary conditions, whereas it increases for Fixed-Hinged boundary conditions. This is due to a decrease in stiffness.



(a) Hinged-hinged: Without holes

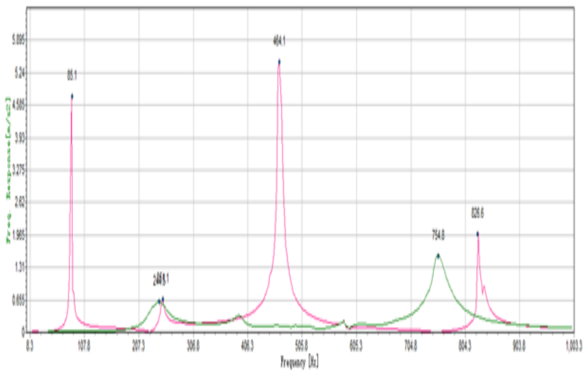


(b) Hinged-hinged: With two holes

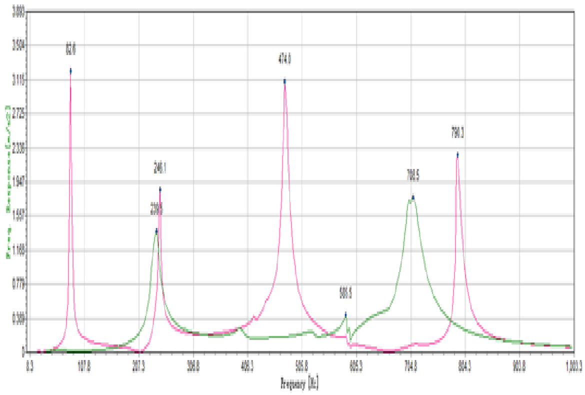


(c) Hinged-hinged: With four holes

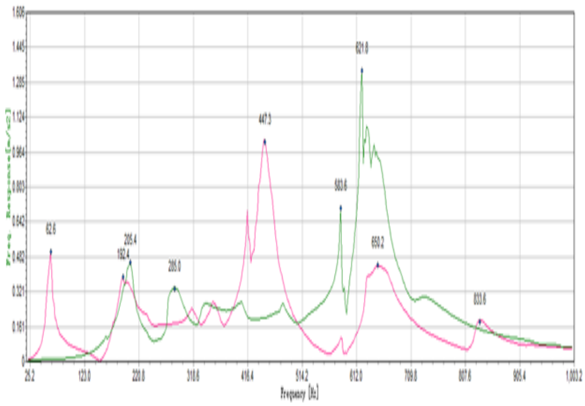
**Figure 3.** Effect of oil damper and number of holes on hinged-hinged boundary conditions



(a) Fixed-free: Without holes

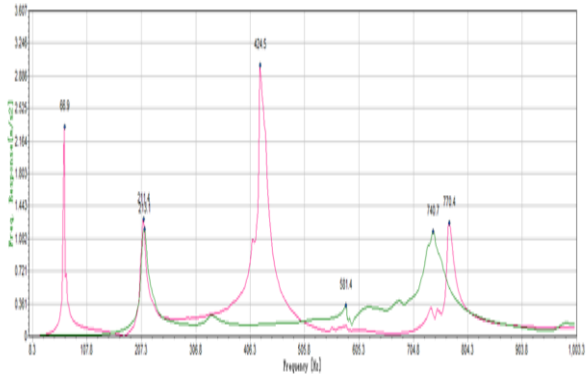


(b) Fixed-free: With two holes

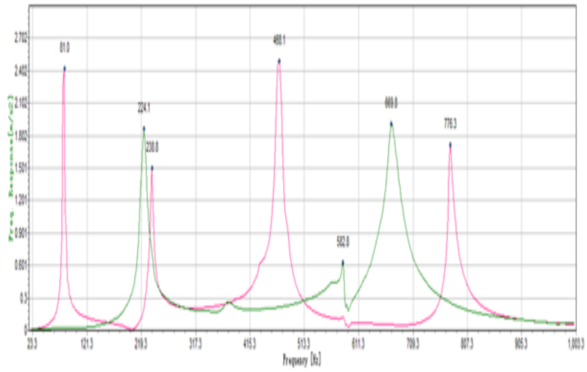


(c) Fixed-free: With four holes

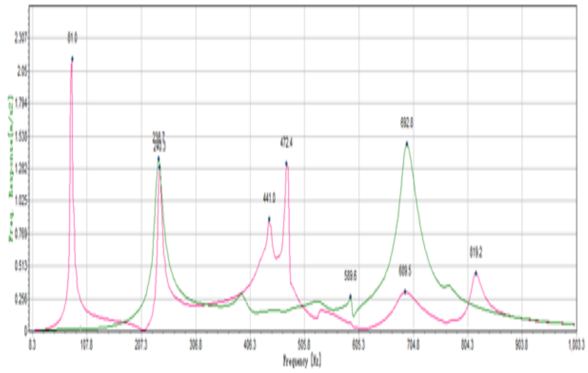
**Figure 4.** Effect of oil damper and number of holes on fixed-free boundary conditions



(a) Fixed-hinged: Without holes



(b) Fixed-hinged: With two holes



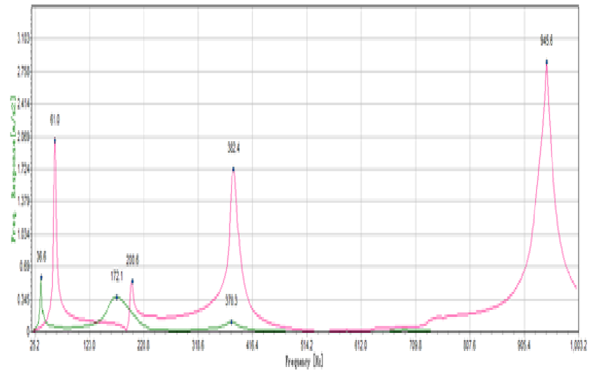
(c) Fixed-hinged: With four holes

**Figure 5.** Effect of oil damper and number of holes on fixed-hinged boundary conditions

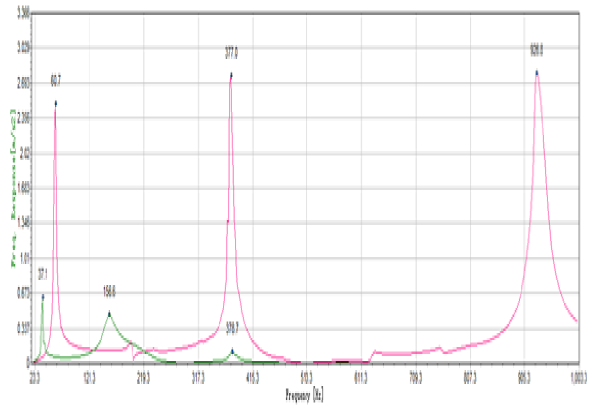
### 3.2 Effect of passive isolator

Natural frequency refers to the frequency at which an object vibrates when it is not being actively forced to vibrate. In the case of a beam, its natural frequency is impacted by several factors, which are illustrated in Figures 6-8. The first factor shown in the figure is the passive isolator, which is a device designed to reduce vibration in the beam. The results of the experiment show that the high frequency of the beam is greatly suppressed by the passive isolator. This means that the isolator is effective at reducing high-frequency vibrations in the beam.

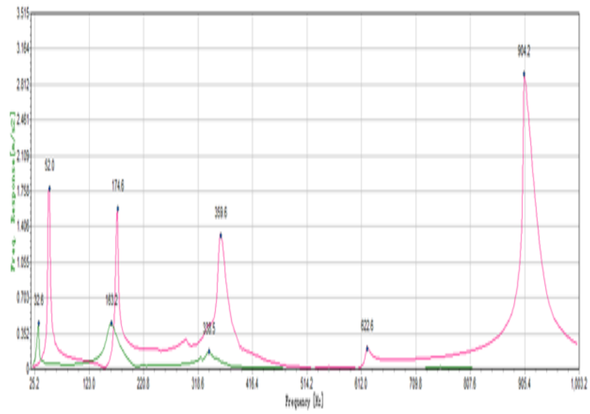
However, the results also show that the lower frequency vibration is amplified due to the self-vibration of rubber absorbers in the isolator. This means that while the isolator is effective at reducing high-frequency vibrations, it can amplify lower frequency vibrations. The second factor shown in the figure is the number of holes on the beam. The results show that the number of holes has a significant effect on the natural frequency of the beam. Specifically, the natural frequency decreases for hinged-hinged and fixed and free boundary conditions when the number of holes is increased. On the other hand, the natural frequency increases for fixed-hinged boundary conditions when the number of holes is increased. This is because the increased number of holes reduces the stiffness of the beam in the direction of the fixed end, which allows the beam to bend more easily in that direction. This increased flexibility results in a higher natural frequency for fixed-hinged boundary conditions. Overall, the natural frequency of the beam is greatly influenced by the presence of an isolator, the boundary conditions, and the number of holes. The maximum and minimum % effect of the isolator were observed to be 44.9% (with four holes and fixed-hinged boundary conditions) and 31.3% (with two holes and fixed-free boundary conditions), respectively.



(a) Hinged-hinged: Without holes

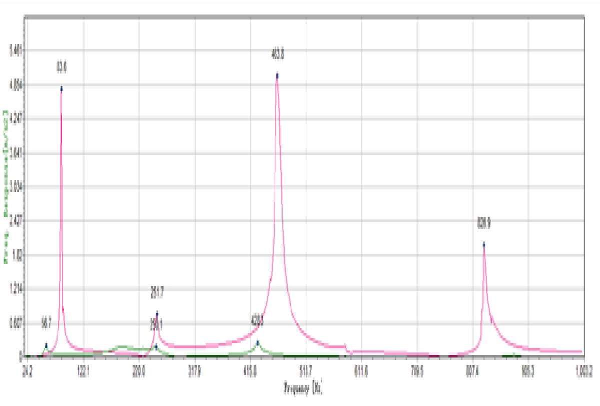


(b) Hinged-hinged: With two holes

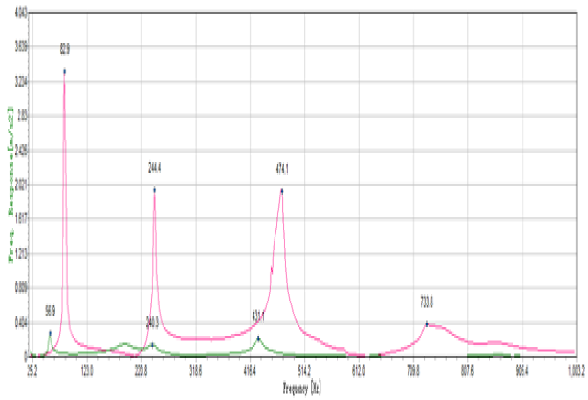


(c) Hinged-hinged: With four holes

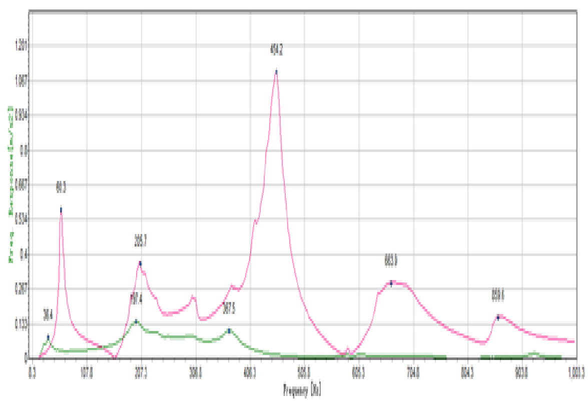
**Figure 6.** Effect of passive isolator and number of holes on hinged-hinged boundary conditions



(a) Fixed-free: Without holes

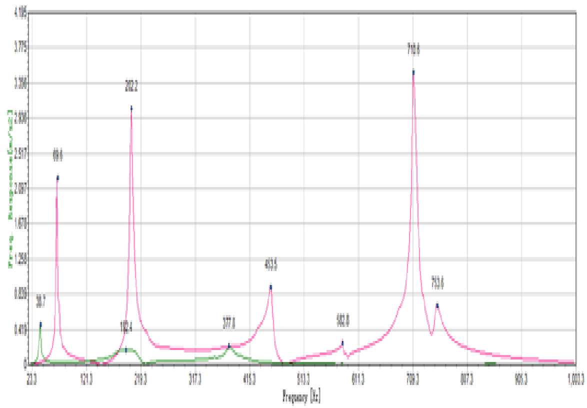


(b) Fixed-free: With two holes

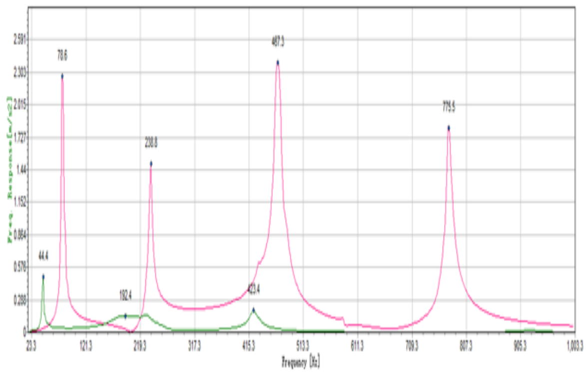


(c) Fixed-free: With four holes

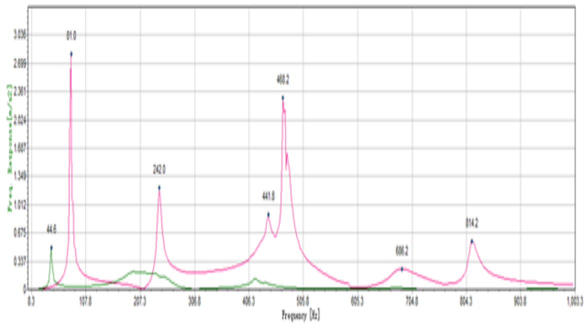
**Figure 7.** Effect of passive isolator and number of holes on fixed - free boundary conditions



(a) Fixed-hinged: Without holes



(b) Fixed-hinged: With two holes



(c) Fixed-hinged: With four holes

**Figure 8.** Effect of passive isolator and number of holes on fixed-hinged boundary conditions

### 3.3 Effect of absorber

Figures 9-10 depicts how the frequency of the beam is affected by the absorbers, number of holes, and boundary conditions. The figures demonstrate that for fixed-hinged boundary conditions, an increase in the number of holes leads to an increase in the frequency of the beam, while for hinged-hinged and fixed-free boundary conditions, it leads to a decrease in frequency. The absorbers have the effect of reducing the amplitude of vibrations, resulting in lower frequencies compared to the primary frequency. It is also observed that for fixed-hinged boundary conditions with two holes, the frequency is reduced by 8.9%. The boundary conditions and absorbers have a significant impact on the frequency of the beam.

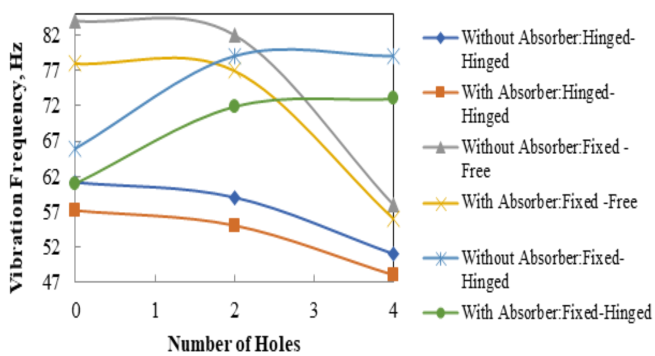



**Figure 9.** Effect of single absorber, number of holes, and end conditions on the vibration frequency

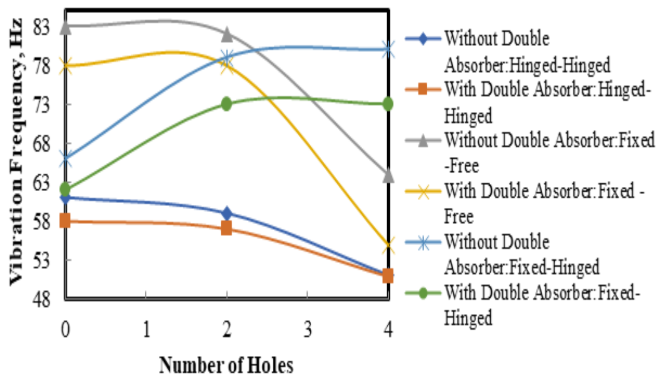



**Figure 10.** Effect of the double absorber, number of holes, and end conditions on the vibration frequency

## 4. CONCLUSIONS

This study examined the impact of the oil damper, absorbers, and isolator on the frequency of the Al6061/SiC composite beam, and the following conclusions were drawn:

- The oil damper is more effective in reducing vibrations compared to the absorber and isolator.
- The absorber, damper, and isolator all have the effect of reducing the amplitudes and frequencies of vibrations.
- Frequencies obtained with the absorber, damper, and isolator are lower than the primary frequency.
- The number of holes in the beam reduces both amplitude and frequency, with the greatest reduction observed for the cantilever beam (fixed-free support condition) with four holes.
- The oil damper, absorber, and isolator are effective in reducing amplitude, with the damper providing the highest reduction in vibration amplitude.
- Overall, the Al6061/SiC composite beam has potential as an alternative to steel.

## ACKNOWLEDGMENT

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