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Experimental study on dynamic behaviour of sandwich beam with composite skin and foam core.

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Abstract
In the present work, a comparative experimental study is conducted on sandwich beams with foam core and Glass Fiber reinforced Epoxy composite (GFRC) skins. Here two types of supporting conditions i.e. a) simple supported b) clamped-clamped are considered for the study. Four sandwich beams with foam core and composite skins with different fiber orientations have been fabricated. The vibration responses have been plotted using the experimental data of frequencies and amplitudes using Matlab to depict the behaviour of the beams. From the graphs, the effect of fiber orientations and supporting conditions have been observed. As the mass of the beam is same, the stiffness changes with GF orientations and supporting conditions, the behaviour of the beam is studied under forced vibrations which gave the clear picture of the applicability and suitability of the said beams keeping in view the present-day engineering applications like rail, road, aerospace and special purpose structures.

Key words:, Glass fiber reinforced composites, skin, foam core, supporting conditions.

1. Introduction

The term sandwich beams refer to composite materials that are reliable for having high tensile strength and stiffness in their characteristics with a comparatively low weight. The characteristics of a sandwich beam include two combatively thin skin layers with the inclusion of thick inner-core.

The sandwich beams are widely used because of the following characteristics:

a. Enhanced Mechanical Properties: Foam cores offer an exceptional benefit by steadily changing their material structure through thickness. This gradient takes into consideration the enhancement of mechanical properties like stiffness and density. In rail, road, and aerospace applications, this component empowers specialists to configure sandwich beams that give the fundamental primary structural rigidity while minimizing weight, contributing to improved efficiency and fuel economy.

b. Damping Control: The capacity to tailor the structure of foam cores takes into account the control of damping characteristics. In the unique examination of sandwich beams, this control is vital for minimizing damping. Foam cores can be intended to have diminished internal friction and hysteresis, leading to lower levels of energy dissipation and, therefore, decreased damping in different designs.

The idea of damping in sandwich beams with Practically Evaluated Material (foam) core is a focal subject in the powerful examination of these designs, especially when the emphasis is on minimizing damping in applications like rail, road, marine, aerospace, and special purpose structures. Damping, in this specific situation, alludes to the dispersal of energy and the decrease of vibrations inside the structure. This is the way the idea of damping is vital concerning sandwich beams with foam cores:

c. Modified Arrangements: Various applications have explicit necessities concerning underlying execution and damping. Foam cores can be redone to satisfy these unique demands. For instance, in marine applications, where vibration control is essential for passenger comfort and equipment durability, Foam cores can be designed to accomplish ideal damping levels without compromising structural integrity.

d. Weight Reduction: Lightweighting is a vital objective in the aerospace and automotive industries. Foam cores, with their capacity to reduce structural weight while keeping up with mechanical integrity, are highly important. The subject of foam core use directly contributes to the decrease of overall structural mass, which, in turn, improves the effectiveness and performance of vehicles and systems.

e. Vibration Control: Damping assumes a critical part in controlling vibrations inside sandwich beams. In rail and road applications, over-the-top vibrations can prompt uneasiness for travellers and speed up mileage on foundation. In aerospace, controlling vibrations is essential for the safety and comfort of passengers and crew. Minimizing damping is critical to accomplishing powerful vibration control.

f. Efficiency and Performance: Diminishing damping is straightforwardly connected with working on the efficiency and performance of vehicles and designs. In aerospace, minimizing damping can prompt diminished fuel utilization and expanded range. In road and rail transportation, it can prompt smoother and more energy-productive rides.

g. Environmental Impact: Lower damping levels can add to natural maintainability. Decreased vibrations and commotion contamination benefit the two travellers and the climate. Also, lower damping can prompt longer-enduring parts, decreasing the requirement for successive substitutions and related asset utilization.

h. Material Selection: Material choice for foam cores is essential in accomplishing the ideal damping qualities. Engineers can tailor the material synthesis inclination inside the foam core to improve damping levels while keeping up with other underlying properties. This fine-tuned material choice is at the core of minimizing damping.

The utilization of sandwich structures is widespread in the fabrication of aerospace, civil, marine, automotive, and other high-performance structures. This is due to their remarkable specific stiffness and strength, exceptional fatigue resistance, extended durability, advantageous vibrational damping capabilities, and numerous other superior properties when compared to conventional metallic beams.

Foam is generated by introducing gas bubbles into plastic by the use of a blowing agent. Laminate foam is manufactured by a continuous process, allowing for the production of varied sizes and forms. However, it is made in batches using different foam cutting equipment. The foam material exhibits exceptional cushioning, support, and protection. It has the benefit of being waterproof and resistant to moisture. Additionally, it demonstrates great heat and thermal insulation capabilities. It is an effective means of achieving shock absorption and impact damping.

For example, the rocket motor may be made with a material system such that the inside of it is made of refractory material. Whereas, the outside of it has to be made of strong materials. transmission from the refractory materials to the metal occurs gradually through the thickness. The use of foam is increasing gradually in automotive, aerospace and biomedical applications. Foam is associated with allowing to inherit the best properties of the two materials which include high thermal resistance from ceramic and low thermal conductivity along with durability and high load resistance from the materials. The use of alloyed materials and geometrical characteristics, Foam cores provide sandwich beams with flexural strength functionality and resistance to damping in practical applications. On the other hand, the application of foam cores increases sandwich beams accuracy and effectiveness making is resistant to vibration damage. The bending capabilities provided by foam cores allow sandwich beams to adapt to structural pressure and prevent cracks and fatal damage.The foam is considered as the core center of the sandwich structure which is exposed to dynamic pressure.

The present-day demand for application of sandwich structures is further augmented with increase in corrosion resistance material by suitable inclusion technique. It has been further proved that their use is versatile due to good acoustic and abrasion resistance properties in desert areas for temporary low-cost applications with safety and other merits.

This literature overview on the sandwich beam and its dynamic behavior is discussed here. In their study, Hassan et. al [1] used the finite element approach to examine the impact of core density on the blast resistance of sandwich panels. The objective was to analyze the strength and toughness of these panels. The approach was also used to forecast the involvement of the core in the energy-absorbing capability of sandwich constructions. Zhou et. al [2] conducted an experiment to investigate the influence of bonding foams with different densities.The finite element analysis was used to forecast the impact response, taking into account the failure characteristics within the models. The resistance to perforation of structures exhibited substantial variation, surpassing that of monolithic equivalents. Li et. al [3] developed a dynamic model to investigate the effects and vibration response properties of fiber reinforced polymers. The use of a thicker carbon filler rod in sandwich plates has been shown to enhance the vibro-impact resistance of the construction.

Ivanez et. al [4] analyzed the dynamic flexural characteristics of a sandwich beam by finite element analysis. The results of the bending tests were consistent with the analytical solution. Upon impact, it was discovered that the top face sheet collapsed in the affected area, hence promoting the hypothesis of maximum displacement and energy absorption. Yurddaskal et. Al [5] conducted a computational and experimental investigation of the curvature and characteristics of foam sandwich panels. The research demonstrated a positive correlation between curvature and foam density with the rise in natural frequency. Once a certain curvature is reached, the inherent frequencies of the foam drop as the foam qualities grow.

Guo et. al [6] conducted numerical simulations to investigate the behavior of an Aluminium foam sandwich plate subjected to repeated impact loads. The experimental findings aligned with the theoretical analysis when subjected to identical conditions. The impact resistance of the plate is influenced by the distribution of thickness on the face sheets. The impact resistance of the plate is influenced by the deflection and energy absorption of both the front and rear face sheets. The deflection and energy absorption of the front and rear face sheets decrease as the thickness of the sandwich plate increases. The study conducted by Zhang et.al [7] examined the effects of low velocity impact on the dynamic collapse of a circular metal foam core, specifically focusing on the splitting and curling modes. The experimental comparison was conducted between the fracture propagation in several strips of sandwich tubes and the analytical technique. The energy absorption of a metal foam core may be estimated by using an appropriate thickness. Waddar et. al [8] performed an experimental investigation on the bending and dynamic response of cenosphere in syntactic foam. The data suggests that the natural frequencies derived from the model analysis exhibit an upward trend as the fly ash cenosphere concentration increases. The load deflection and natural frequencies exhibit a high level of concordance. Wang et.al [9] constructed a design model for foam core sandwich panels by considering structural responses, deformation modes, blast resistance, and energy absorption requirements. This design is optimized based on the Pareto solution, resulting in improved weight efficiency. Zhou et. al [10] enhanced the design of graded core sandwich structures by optimization.A comparison was made between the finite element analytical solution of the sandwich panel and experimental data, demonstrating a strong agreement. The research demonstrated the superior blast resistance of uniform core sandwich panels compared to graded core sandwich panels. This finding offers valuable insights into the engineering applications of sandwich structures with multi-layer cores under air blast stress.In their study, Breunig et. al [11] examined the effect of cenosphere volume on the behavior of syntactic foam core sandwich composites when subjected to dynamic stress. Additionally, the researchers investigate several damage causes and construct a finite element model using different volume percentages. Hodge et. al [12] implemented a thermal protection system to ensure the structural integrity of the hardware and shield it from the effects of aerodynamic heating. This study offers valuable insights into the use of metal/TPS with polymer composites for sandwich system applications in the carbon epoxy skin of both the outer and inner faces of the foam core. Barbieri et. al [13] used the finite element technique and Timoshenko beam theory to simulate domestic freezers made of polyurethane rigid foam and high impact polystyrene. This is based on the calculation of Young's modulus and loss factor of polystyrene and polyurethane rigid foam. Caliskan and Apalak [14] investigated the effects of low-velocity impact on the face sheets of sandwich beams with low-density foam cores. The impact test was confirmed by finite element analysis to determine the temporal contact force and permanent central deflections. Hajikhani et.al [15] evaluated the liberation of strain energy in the mode one separation of foam core sandwich composite using sonic emission. The interlaminar fracture energy is influenced by the stacking sequence, material properties, and manufacturing method. It was evaluated using ASTM procedures and shown to be effective. In their study, Salleh et.al [16] examined the tensile, compressive, and flexural properties of sandwich panels with a syntactic foam core. They also expected that the tensile and compressive strength would decrease as the microballoon concentration increased. By carefully incorporating microballoons, the addition of Vinyl Ester may significantly improve the overall tensile, compressive, and flexural strength. In their study, Mu et.al [17] conducted a two-dimensional dynamic analysis on sandwich plates that had functionally graded foam cores. The research focused on the response of the plates to time-dependent impulse forces. Analyzed using a finite element model, the core material with gradient foam exhibited varying properties across its thickness. An investigation was conducted on the natural frequency, deflection, and energy absorption of a sandwich plate with a foam gradient core. Nejd et.al [18] conducted an experimental and computational investigation on the behavior of pin-reinforced foam core under indentation and mild impact loading conditions. The research demonstrated that the flexural strength of the foam core was enhanced when reinforced with pins, particularly under impact loading conditions. Subsequently, the design is enhanced specifically for sandwich panels. Komorek et.al [19] used Herex and Airex polymers as the central cores in composite sandwich constructions, with the faces composed of fabric layers consisting of glass and carbon. This kind of core, which is thicker and denser, has exceptional impact strength and resistance to punctures. Damage in this sandwich composite only occurs in the layer under low-energy impact loading. Hua and Wang [20] examined the use of a metal foam core sandwich beam to study dynamic big deflection. The low-velocity heavy mass impact response of completely clamped sandwich beams is predicted by observing the numerical solution using finite element analysis for various examples of mass ratio, impact velocity, and position. Sunet.al [21] conducted an experiment to investigate the dynamic behavior of foam sandwich panels subjected to impulse blasting, using various combinations of face sheets and core gradients. The findings indicate that sandwich panels with a positive gradient of core density outperform those with a negative gradient of core density. The performance is directly proportional to the density difference. A positively graded core demonstrates greater resistance to blasting in comparison to a uniform core. In their study, Xionget.al [22] conducted a comprehensive analysis of the characterization of sandwich constructions that use corrugated honeycomb and foam cores. The primary emphasis was placed on strengthening the bonding between the core and face materials, improving the mechanical characteristics of both the core and panel, and exploring prospective applications such as morphing wing design, impact resistance, and ultra lightweight uses.Yanget.al [23] examined how temperature affects the damage caused by low velocity impacts in sandwich panels with a core made of polymeric foam. The damage seen in the core and face sheets at high temperature conditions are mostly caused by tensile failure, without any occurrence of fiber fracture.

2. Fabrication of sandwich beam process

A sandwich beam consists of a top and a bottom skin and a core(soft/stiff). For preparing the skin, a procedure is described below for a particular Glass Fiber orientation and the same procedure is repeated for other orientations of GF of skin.

First of all, the dimensions of sandwich beams are 60cm(L)X3cm width(W)X13mm thick. The top and bottom skins are 3mm thick and they are pasted to the sandwich core of 5mm thick and the paste thickness is 2mm approximately which comes to13mm as a whole.

Procedure: A transparent sheet of 70cm (L) X 30 cm (W) is placed over a plane table with corners applied cello tapes to keep intact. Then the 5 pieces GF mats are weighed in digital balance which are 360 GSM type A which was 500 gm weight in my case. Then Epoxy of grade GY 250 and binder of HY 951 are mixed in equal portion to 500gm by weight. A coat of epoxy and binder solution is applied in the transparent sheet as mentioned above and a hand roller is applied all around to spread the solution uniformly and evenly. Then first piece of GF mat was placed over this and roller is rolled to make it proper shape of our desired dimension and again the solution is applied with brush and the roller is rolled all around to make the spread of solution evenly and uniformly. The same procedure is applied for five numbers of GF mats and the solution is applied each time as described above. After this a transparent sheet is covered on top layer and above it a wooden plank is placed on it.Six pieces of bricks are kept over the plank to make uniform loading to the composite so fabricated and allowed it for 48 hours in closed chamber to make it free from flaws, porosity, air bubbles. Then it is cut in grinding wheel to our required dimension and pasted to core. This way for a particular type of sandwich beam is prepared and the procedure is repeated for other orientations of GF reinforcement and fabrication of ensuing skins.

3. Working procedure of experiments

The beam is given an excitation of 1Hz at one end and the probe is placed at mid of gauge length of specimen of 50.4 cm. The probe along with accelerometer is attached and for each frequency against amplitude reading are noted as shown in the set up for the above supporting conditions. The resonance amplitude and its frequency is shown in graphs plotted for the same beam under probe at mid and supporting end location. As the mass of the beam is same, the natural frequency is related to the square root of the beam stiffness. which in turn depends on the fiber orientation. A comparison of behaviour of different orientation of reinforcement is studied experimentally from the graph.For experiment we have considered two supporting conditions i.e simply supported and clamped clamped categories. Four beams with composite skins of different fiber orientations have been taken to study the dynamic behaviour experimentally.

4. Results and discussions

Various experiments have been conducted and the results are discussed.

4.1. Supporting condition: Simple Supported Beam

Fig 4.1 Experimental set up

Fig 4.1 shows the experimental set up for forced vibration of sandwich beam with simply supported end condition. In Fig 4.1(a) the sandwich beam’s vibration response with composite skin with fiber orientation 0^0.The probe is placed at midpoint and support end of the specimen. It is observed that the resonant occurs at the frequency of 11Hzwhen the probe is at the midpoint. When the probe is at the support end, the resonance occurs at the frequency of 1Hz The resonance frequency is more when the probe is at support end since the beam is more stiff near the support end.

In Fig 4.1(b) the sandwich beam’s vibration response with composite skin with fiber orientation 15^0. The probe is placed at midpoint and support end of the specimen. It is observed that the resonant occurs at the frequency of 12Hzwhen the probe is at the midpoint. When the probe is at the support end, the resonance occurs

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at the frequency of 18Hz The resonance frequency is more when the probe is at support end since the beam is more stiff near the support end..

In Fig 4.1(c) the sandwich beam's vibration response with composite skin with fiber orientation 30^0. The probe is placed at midpoint and support end of the specimen. It is observed that the resonant occurs at the frequency of 12Hz when the probe is at the midpoint. When the probe is at the support end, the resonance occurs at the frequency of 21Hz The resonance frequency is more when the probe is at support end since the beam is more stiff near the support end..

In Fig 4.1(d) the sandwich beam's vibration response with composite skin with fiber orientation 45^0. The probe is placed at midpoint and support end of the specimen. It is observed that the resonant occurs at the frequency of 13Hzwhen the probe is at the midpoint. When the probe is at the support end, the resonance occurs at the frequency of 2Hz The resonance frequency is more when the probe is at support end since the beam is more stiff near the support end.

From the above experiment, it is observed that as the GF orientation is increased the beam becomes stiff and the resonant amplitudes and frequencies are increasing as compared to 0^0 of GF orientation.

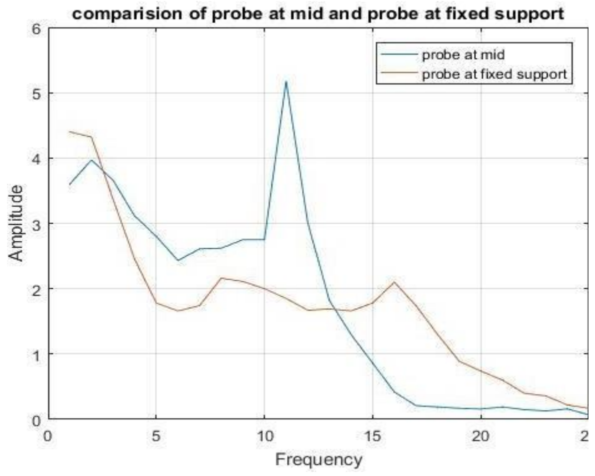

Fig 4.1 (a) Sandwich beam's vibration response with foam core and composite skin with 0^0 fiber orientation

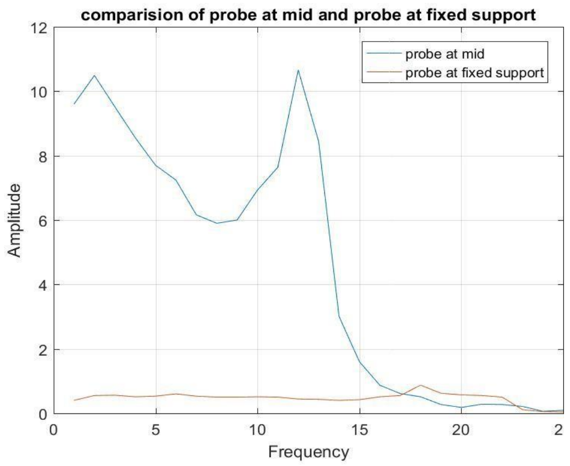

Fig 4.1 (b) Sandwich beam's vibration response with foam core and composite skin with 15^0 fiber orientation

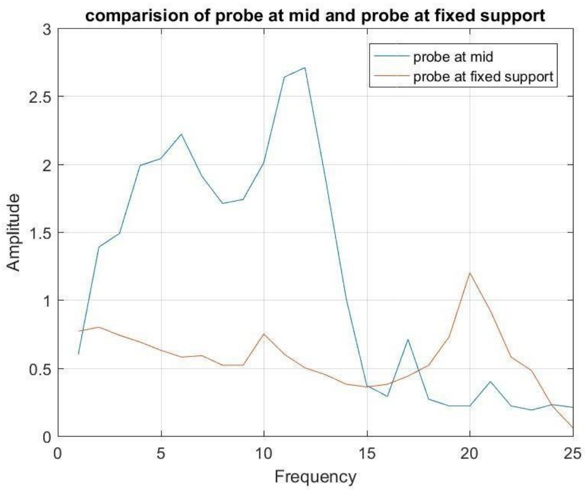

Fig 4.1 (c) Sandwich beam's vibration response with foam core and composite skin with 30^0 fiber orientation

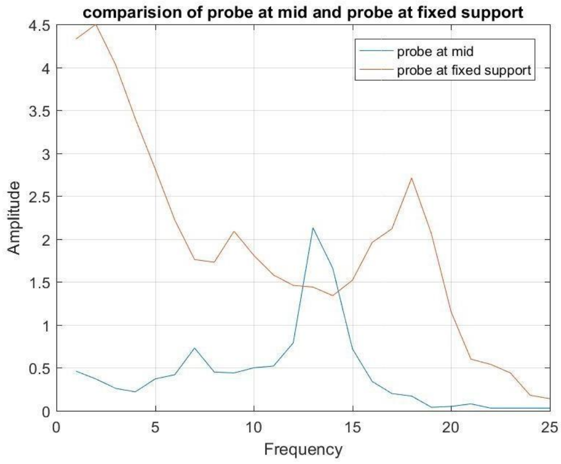

Fig 4.1 (d) Sandwich beam's vibration response with foam core and composite skin with 45^0 fiber orientation

4.2. Supporting conditions: Clamped clamped condition (both ends clamped)

Fig 4.2(a) Experimental set up

Fig 4.2(b) Experimental set up

Fig. 4.2 (a) and (b) depict the experimental arrangement for inducing forced vibration in a sandwich beam. The beam is clamped at both ends and the probe is positioned at the midpoint and the clamped end of the specimen. The vibration response of a sandwich beam with a composite skin and fiber orientation of 0^0 is shown in Fig. 4.2(c). The probe is placed at midpoint and support end of the specimen. It is observed that the resonant occurs at the frequency of 15 Hz when the probe is at the midpoint. When the probe is at the support end, the resonance occurs at the frequency of 2Hz The resonance frequency is more when the probe is at support end since the beam is more stiff near the support end.

In Fig 4.2(d) the sandwich beam’s vibration response with composite skin with fiber orientation 15^0. The probe is placed at midpoint and support end of the specimen. It is observed that the resonant occurs at the frequency of 12Hzwhen the probe is at the midpoint. When the probe is at the support end, the resonance occurs at the frequency of 2Hz The resonance frequency is more when the probe is at support end since the beam is more stiff near the support end.

In Fig 4.2(e) the sandwich beam’s vibration response with composite skin with fiber orientation 30^0. The probe is placed at midpoint and support end of the specimen. It is observed that the resonant occurs at the frequency of 5Hzwhen the probe is at the midpoint. When the probe is at the support end, the resonance occurs at the frequency of 3Hz. The resonance frequency is more when the probe is at support end since the beam is stiffer near the support end.

In Fig 4.2(f) the sandwich beam’s vibration response with composite skin with fiber orientation 45^0. The probe is placed at midpoint and support end of the specimen. It is observed that the resonant occurs at the frequency of 4 and 5Hzwhen the probe is at the midpoint. When the probe is at the support end, the resonance occurs at the frequency of 3 and 4Hz. The resonance frequency is more when the probe is at support end since the beam is stiffer near the support end.

From the above experiment, it is observed that as the degree of GF orientation is increased the beam becomes stiff and the resonant amplitudes and frequencies are shifted to higher values as compared to 0 degree of GF orientation.

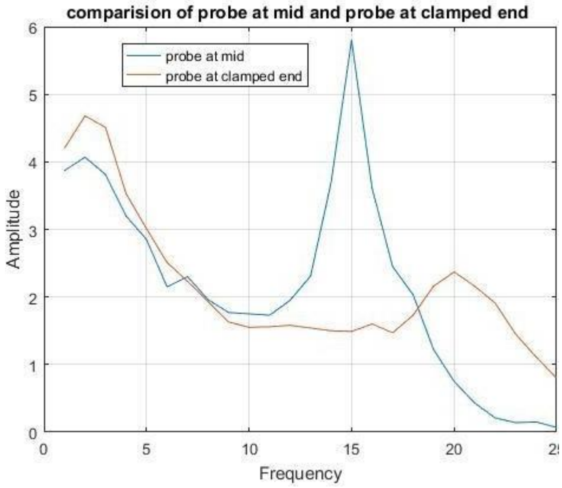

Fig 4.2 (a) Sandwich beam’s response with foam core and composite skin with 0^0 fiber orientation

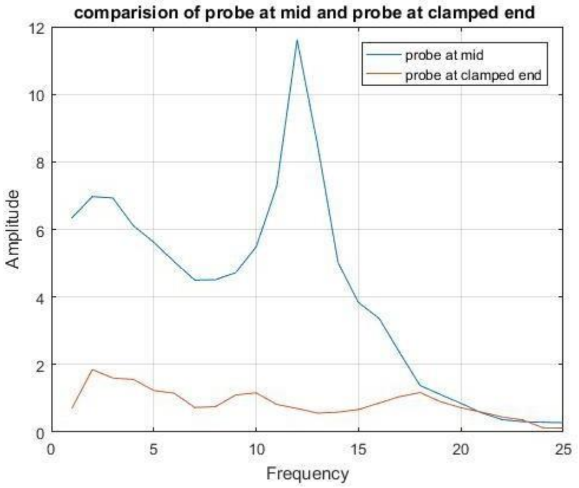

Fig 4.2 (b) Sandwich beam’s response with foam core and composite skin with 15^0 fiber orientation

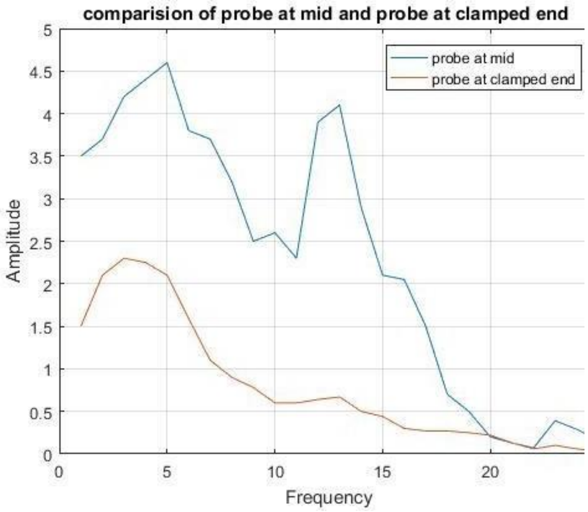

Fig 4.2 (c) Sandwich beam’s response with foam core and composite skin with 30^0 fiber orientation

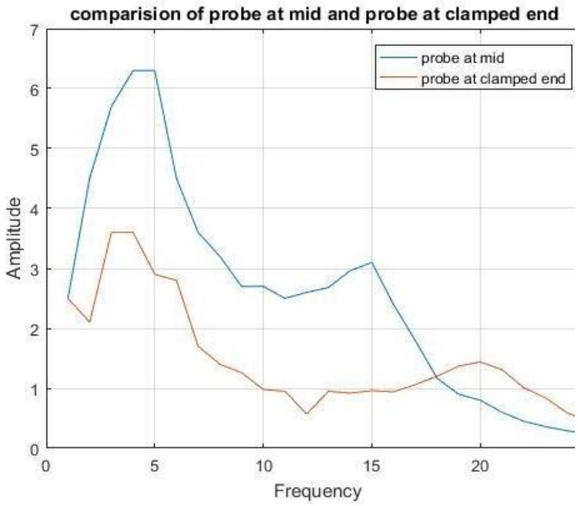

Fig 4.2 (d) Sandwich beam’s response with foam core and composite skin with 45^0 fiber orientation

5. Comparison of frequencies

Table 1

Fiber Orientation	Simply Supported		Clamped clamped	
	Probe at mid	Probe at Support end	Probe at mid	Probe at Support end
0^o	15 Hz	2Hz	15 Hz	2 Hz
15^o	12 Hz	2 Hz	12 Hz	2Hz
30^o	5 Hz	3 Hz	5 Hz	3 Hz
45^o	13 Hz	2 Hz	4,5Hz	3,4Hz

6. Conclusion

The present study confirms that when the probe is placed at the middle of the specimen in simply supported condition, the resonant frequencies obtained are at 15Hz,12Hz,5Hz and 13Hz for fiber orientations of 0^0,15^0, 30^0,and 45^0 respectively. Similarly, when the probe is placed near the support end, the resonant frequencies are 1Hz, 18Hz, 21Hz and 2Hz for fiber orientations of 0^0,15^0,30^0, and 45^0 respectively. This happens because as we move the probe towards the support end,the beam becomes stiffer and the resonance occurs at lower frequencies.

Similarly, when the probe is placed at the mid of the specimen in clamped clamped end, the resonant occurs at frequency of 15Hz, 12Hz, 5Hz and 4Hz and 5Hz for fiber orientations of 0^0,15^0,30^0 and 45^0 respectively. Similarly, when the probe is placed near the support end,the resonant frequencies are 2Hz, 2Hz, 3Hz and 4Hz for fiber orientations of 0^0,15^0, 30^0, and 45^0 respectively. This is because the beam is stiffer near the support end and resonant occurs at lower frequencies.

From the table shown, it is clear that as the fiber orientation is increased, the beam becomes stiffer and resonant occurs at lesser frequencies. Hence it is concluded that resonance depends on fiber orientation and location of probe with respect to end supporting conditions.

This present study mainly focused on sandwich beams comprised of a composite outer layer as well as a foam core. Researchers of this domain investigate how these beams respond to dynamic forces, like vibrations, as well as their structural integrity. With the examination of their behaviour under various conditions, such as environmental factors and imperfections factors, this literature review mainly aims to enhance the understanding of these materials, which have applications in industries ranging from aerospace to construction.

In the present experimentally work, sandwich beams with composite skins and foam core are fabricated. Four beams have been fabricated with different fiber orientations and foam core. Various experiments have been conducted considering two support conditions i.e simply supported and clamped clamped. From the result and discussion, it has been observed with increase in fiber orientation there is increase in stiffness andchange of resonancefrequencies. This experimental study may help the designers to design the sandwich structures for various applications in engineering field.

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