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EXPERIMENTAL STUDY ON DYNAMIC BEHAVIOUR OF SANDWICH BEAM WITH COMPOSITE SKIN AND FGM CORE.

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Abstract

In the present work, a comparative experimental study is conducted on sandwich beams with FGM 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 FGM 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: Functional Graded Material, Glass fiber reinforced composites, skin, 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: FGM 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 FGM cores takes into account the control of damping characteristics. In the unique examination of sandwich beams, this control is vital for minimizing damping. FGM 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 (FGM) 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 FGM cores:

c. Modified Arrangements: Various applications have explicit necessities concerning underlying execution and damping. FGM 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, FGM 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. FGM cores, with their capacity to reduce structural weight while keeping up with mechanical integrity, are highly important. The subject of FGM 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 travelers 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 travelers 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 FGM cores is essential in accomplishing the ideal damping qualities. Engineers can tailor the material synthesis inclination inside the FGM core to improve damping levels while keeping up with other underlying properties. This fine-tuned material choice is at the core of minimizing damping.

Sandwich structures are extensively used in the construction of aerospace, civil, marine, automotive and other high-performance structures due to their high specific stiffness and strength, excellent fatigue resistance, long durability, good vibrational damping advantages and many other superior properties compared to the conventional metallic beams. 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.

The following session gives the literature survey on sandwich beam and dynamic behavior.

Salem et. al [1] found that the FGM beam fabricated out of 3d printing are subjected to buckling loads and the experimental results concur similar to theoretical calculation to maximum approximation. The above bilateral constrained beams are optimised with material functions in different applications. Quang et. al [2] used piezoelectric sensors actuators for FGM plates. The static and dynamic vibration of the plates are in line with accurate result of experimental and theoretical calculations. [3] Zhen et. al predicted the behaviour of sandwich beam with Electro Rheological Fluid (ERF). The investigations revealed the analysis and formulation have great accuracy and efficacy with one another.

Zhen et. al [4] observed the dynamic behaviour of FGM made up of pipes carrying fluids wherein the non-linear vibration considered for theoretical application with dynamic equations by Hamilton's principle using Euler Bernouli and Timoshenko theories. Khersoni et. al [5] presented the derivation using Hamilton's variable principle for size of FGM plates presented the derivation using Hamilton's variable principle for size of FGM plates with controlled piezoelectric layers which are in conjunction with higher order kinematics deduced by Reddy's theoretical formulations.

Foroutan et. al [6] investigated the non-linear free vibration and hygrothermal buckling behaviour of carbon nano tubes of imperfect FGM panels and inferred the effects of temperature, moisture, non-linear visco-elastic foundations of initial imperfections and material parameters in free vibrations and its buckling behaviour of above tubes. Singh et.al [7] developed procedure for increasing the life of thermos setting FGM which are polymer based for low temperature applications. The interfacial adhesion between between fiber and matrix is enhanced by inclusion of Kevlar fiber, carbon fiber and Silica which increases mechanical strength and hardness. Photopolymerisation and Sedimentation technique eliminates the drawbacks like stress concentration which increase the versatile use due to changes in thermal and electrical stress.Lavanjari et. al [8] postulated the use of FGM in thermal applications by adopting piezoelectric materials for studying the behaviour of sensors and actuators. By simulating FGM with Finite Element Analysis, the materials like ceramic, metal and piezoelectric materials in layers, the the response of actuators and sensors are enhanced. Doddamani et.al [9] analysed the jute epoxy sandwiches reinforced by fly ash to make the FGM more flexible and compliant. The damping ratio and natural frequency are measured which are optimised using experimental Taguchi design for predicting the properties in sandwiches which are validated experimentally. Chedad et. al [10] studied the behaviour of FGM plate bonded with concrete and later on extended interfacial stress analysis to all kind of materials reinforced with thin plates. The geometrical parameters of material affect the normal and shear stress of composite beams. A comparative analysis of existing and the newly developed method is done and found that the strength and flexural behaviour is improved. Njim et. al [11] analytically provided solution of free vibration to sandwich plates with porous FG metallic material and two homogeneous skins. Using classical plate theory, the porosity and power gradient affects the vibration characteristics which were validated accurately by using finite element analysis adeptly. This method helped to develop a 3D printed FGM with two solid face sheets at top and bottom. Banerjee et.al [12] corelates the role of nano tubes reinforced composites in the manufacture of ship hull, gas turbine blades because of physical and material characteristics when they are reinforced with FGM. The static and dynamic vibrational characteristics will decide its use for the above-mentioned applications applying structural reinforcement technique to enhance their usage in modern engineering applications. Sharma and Bhandari [13] provided an elastic solution for a sandwich beam with FG core by dividing the core into two halves and applied Euler Bernouli theorem. The analysis revealed the variation of Young’s modulus exponentially with thickness from mid to interface of core. Further analysis proved that shear stress reduction in core/face sheet interface by inclusion of FG material core. The normal stress varies linearly through the thickness of FG core and is independent of properties. Njim et. al [14] devised method to find the variation of porosity in affecting the micro-structure and mechanical properties which was verified experimentally. The performance variation is further augmented by finite element analysis and ANSYS simulation. The index of gradient and porosity enhance the resistance to bending by inclusion of nano particles and its static behaviour significantly. Meksi et. al [15] used Hamilton principle for studying the transverse shear stress of rectangular sandwich plates along with Navier solution method. The solution thus deduced concurred for studying critical buckling load, deflections, stresses and natural frequencies of functionally graded sandwich plates. Sayyidmousavi et. al [16] investigated sandwich polymer beams with FG face sheets and reinforced carbon nanotubes subjected to successive moving harmonic loads. Using 2D theory of elasticity, the effects of velocity, position, excitation frequency and phase angle of loads were analysed and inferred to have increased flexural rigidity with increase of volume fraction which later on can be designed for optimum sandwich structure under complicated loading. Rabboh et. al [17] analysed the dynamic behaviour of laminated composite beams using different fiber orientations and dynamic excitation methodology harmonic response. The study showed the decrease in natural frequency with increased fiber orientations and increase in natural frequency with increased thickness which is a deciding factor for control of vibration.

Wang et. al [18] developed a polymer-based nanocomposite reinforced with graphene nanoplates following gradient index which resulted in improved mechanical properties. The above developed sandwich structure when studied under third order shear deformation theory for bending aand vibrational applications which showed an improved pattern in mechanical properties than common ones.

Njim et. al [19] developed stability and free vibration analysis and application of FGM in rectangular plates. The analysis of vibration and buckling depending on gradient index, aspect ratio, face sheet thickness, porous factor, FGM layer thickness and number of layers provided an insight for future development. Njim et. al [20] experimented on FGM structures on bending stiffness and shear stress simultaneously which depends on impact, core weight, materials, power law index and skin thickness for suitability of application like aerospace and marine sectors depending flexural rigidity and performance parameters. Wang et. al [21] observed the FGM OF Nickel and steel with property graded in thickness direction following power law distribution. The translational FGM plate shows intensive hardening characteristic which affects damping coefficient and excitation amplitude for non-linear dynamic response in parametric study. Furjan et al. [22] studied the porous FGM and magneto strictive nanocomposite layers for the wing in improving stiffness and controlling wave propagation. By imposing magnetic field on magneto strictive layer, the wave velocity is increased based on core and face sheet thickness, damping structure and size parameters.

From the above references, it is concluded that modern engineering application needs sandwich structure with good material characteristics than conventional metallic material for deciding its application which can be suited depending on the situations and cost factor as well.

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)X30cm(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 fixed end location. As the mass of the beam is same, the natural frequency is directly proportional to square root of stiffness of the beam which in turn depends the giber orientation. A comparison of behaviour of different orientation of reinforcement is studied experimentally from the graph which helps in calculating the natural frequency. 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

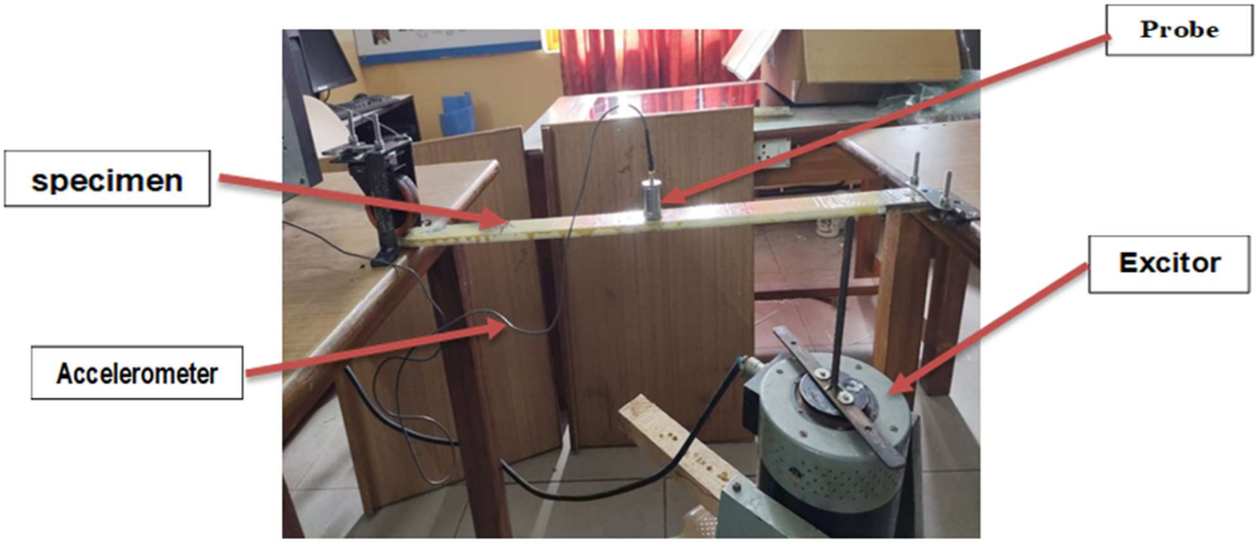


Fig 4.1 Experimental set up

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 vibration response of sandwich beam 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 3Hzwhen the probe is at the midpoint. When the probe is at the support end, the resonance occurs at the frequency of 13Hz.The resonance frequency is more when the probe is at support end since the beam is stiffer near the support end.

Fig 4.1(b) shows the vibration response of sandwich beam 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 15Hzwhen the probe is at the midpoint. When the probe is at the support end, the resonance occurs at the frequency of 19Hz. The resonance frequency is more when the probe is at support end since the beam is more stiff near the support end.

Fig 4.1(c) shows the vibration response of sandwich beam 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 12Hzwhen the probe is at the midpoint. When the probe is at the support end, the resonance occurs at the frequency of 13Hz.The resonance frequency is more when the probe is at support end since the beam is stiffer near the support end.

Fig 4.1(d) shows the vibration response of sandwich beam 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 2Hzwhen the probe is at the midpoint. When the probe is at the support end, the resonance occurs at the frequency of 5Hz. 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 GF orientation is increased the beam becomes stiffer and the resonant frequencies are increasing as compared to 0^0 of GF orientation.

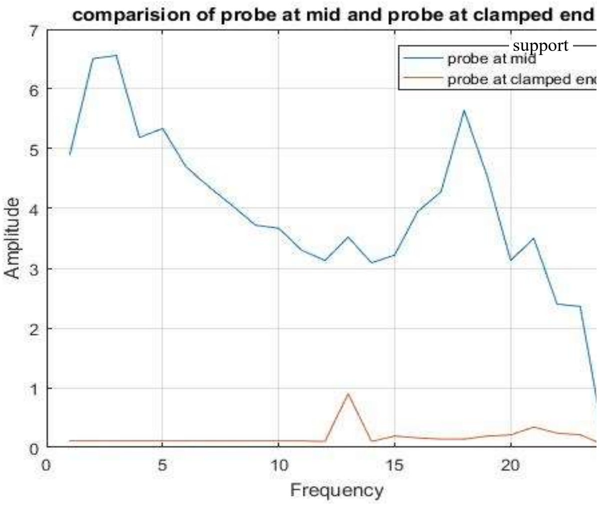


Fig 4.1 (a) Response of sandwich beam with

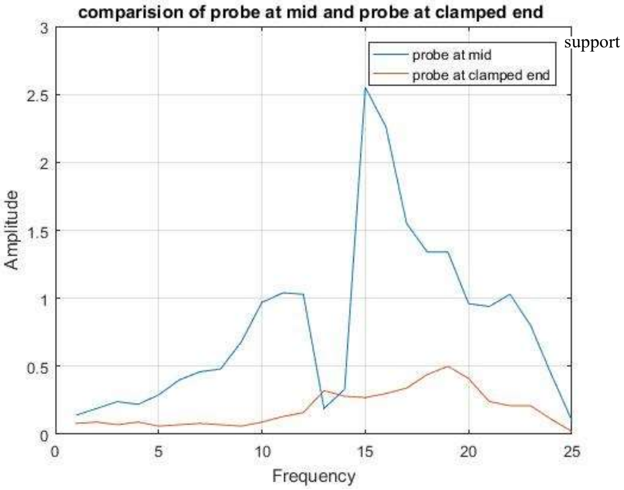
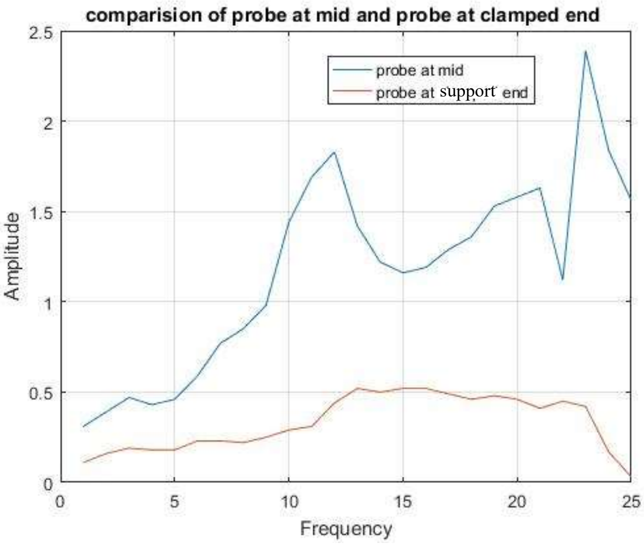


Fig 4.1 (b) Response of sandwich beam

with

FGM core and composite skin FGM core and composite skin

with 0^0 fiber orientation with 15^0 fiber orientation



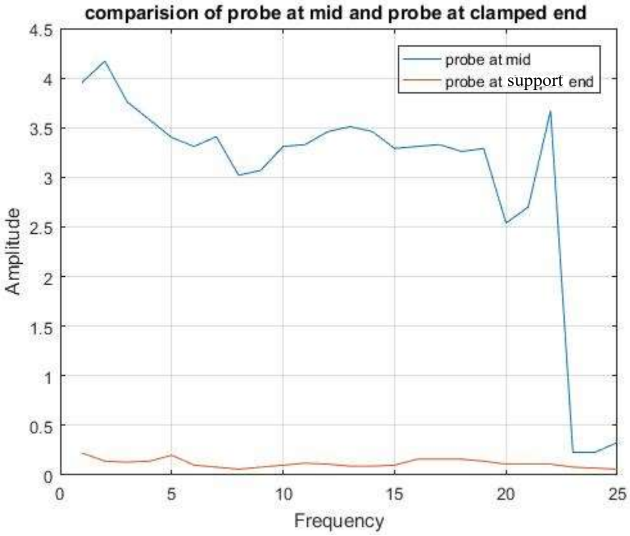


Fig 4.1 (c) Response of sandwich beam with Fig 4.1 (d) Response of sandwich beam
with

FGM core and composite skin FGM core and composite skin

with 30^0 fiber orientation with 45^0 fiber orientation

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

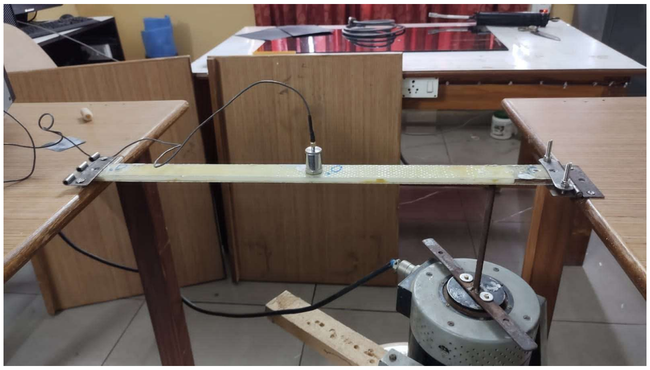


Fig 4.2(a) Experimental set up

Fig 4.2(b) Experimental set up

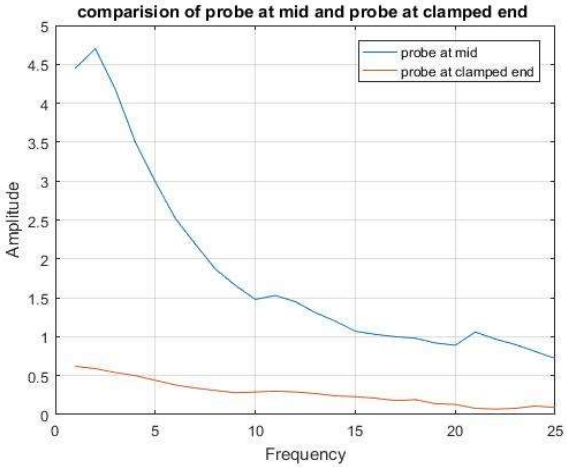
Fig 4.2 (a) and (b) show the experimental set up for forced vibration of sandwich beam with clamped- clamped supported end condition when the probe is placed at mid pint and clamped end of the specimen. Fig 4.2(c) shows the vibration response of sandwich beam with composite skin with fiber orientation 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 2Hzwhen 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 stiffer near the clamped end.

Fig 4.2(d) shows the vibration response of sandwich beam 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 2Hzwhen 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 stiffer near the clamped end.

Fig 4.2(e) shows the vibration response of sandwich beam 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 16Hzwhen 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 stiffer near the clamped end.

I Fig 4.2(f) shows the vibration response of sandwich beam 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 20Hzwhen 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 stiffer near the clamped 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 increasing as compared to 0^0 of GF orientation.



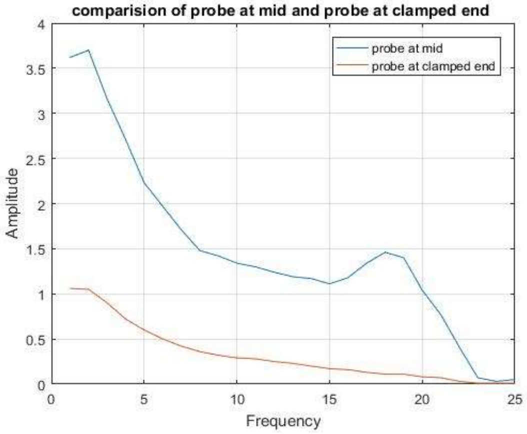
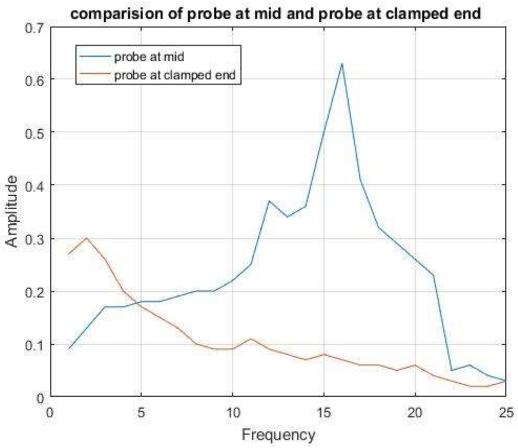


Fig 4.2 (c) Response of sandwich beam with with FGM core and composite skin with 0^0 fiber orientation

Fig 4.2 (d) Response of sandwich beam FGM core and composite skin with 15^0 fiber orientation



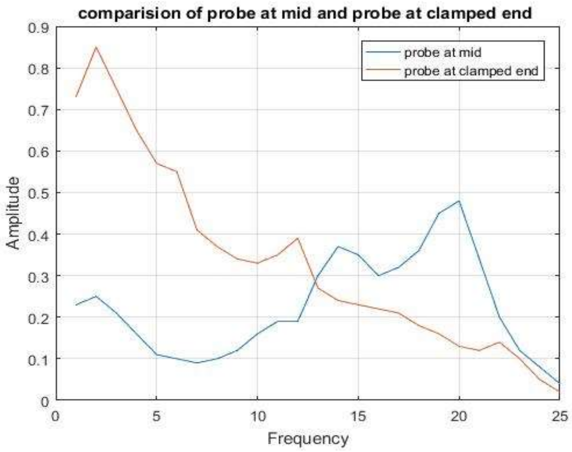


Fig 4.2 (e) Response of sandwich beam with with FGM core and composite skin with 30^0 fiber orientation

Fig 4.2 (f) Response of sandwich beam FGM core and composite skin with 45^0 fiber orientation

5. Conclusion

FGM or functionally graded materials are usually manufactured with ceramic and metals by following a specific fraction of the materials. The FGM poses properties which gradually with the location of the materials. 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 FGM is increasing gradually in automotive, aerospace and biomedical applications. FGM 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, FGM cores provide Sandwich beams with flexural strength functionality and resistance to damping in practical applications. On the other hand, the application of FGM cores increases Sandwich beams accuracy and effectiveness making is resistant to vibration damage. The bending capabilities provided by FGM cores allow sandwich beams to adapt to structural pressure and prevent cracks and fatal damage. The FGM is considered as the core center of the sandwich structure which is exposed to dynamic pressure. The functionally graded materials are those particular materials in which the change of the properties occurs from one point to another within them.

This literature review mainly focused on sandwich beams comprised of a composite outer layer as well as a Functionally Graded Material (FGM) 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.

From the experimental study it is observed that fiber orientation increases the stiffness of the sandwich beam and accordingly the resonance frequencies change. This study helps in designing the design of robot arms, manipulators other applications in aerospace and design of vibration absorbers.

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