ANALYSIS OF THIN-WALLED LAMINATED COMPOSITE I-SECTON BEAMS

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Abstract: In structural applications, beam is one of the most common structural members that have been considered in design. For the last three to four decades mechanical vibrations have been recognized as a major factor in the design. The present work particularly deals with dynamic analysis of lengthy uniform thin-walled uniform I-beams, and the analytical model developed by Lee and Kim [13] is taken and the dynamic behavior of a thin-walled I-section composite beam is studied in detail. Equations of motion are derived from Hamilton's principle. Numerical results are obtained for thin-walled composite beams addressing the effects of fiber angle and boundary conditions on the vibration frequencies and mode shapes of the composites. Using ANSYS 15.0, the modal analysis are carried out and presented in graphical form. Compared to the steel beam, the composite beam has frequency that are much satisfied, The results show the stacking sequence and fibre angle orientation strongly affects strength of composite I-beam.

Index Terms: **Model analysis, composite structures, I-Section, composite beam**

I. INTRODUCTION

The demands on material performance are so great and diverse that no one material is able to satisfy them(lightweight yet strong and stiff structures).composite material systems results in a performance unattainable by the individual constituents. Composite materials offer the advantage of a flexible design that can be tailored to the design requirements by Bob Mathews [1]

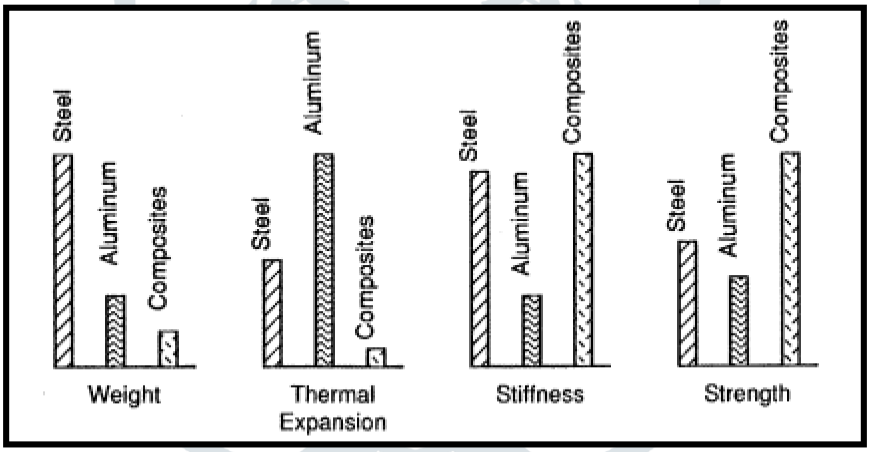


Figure 1: Comparison of composite materials

Ashish A. Desai [2] presented that composite materials are used in many fields of industry. Composites are widely used in the automobile, aerospace, and athletics industry. Examples of composites include bumpers, wings, bicycle frames, and downhill skis. In the literature survey, it is found that thin-walled beams of open cross-section, such as I-section beams, are susceptible to instability in a variety of modes, but a few publication have dealt with dynamic behaviour of such members. Closed-form solution for flexural and torsional natural frequencies of isotropic thin-walled beams is found in the literature [3-5]. Several papers were devoted to the application of composite materials for automobiles. Rajendran and Vijayarangan [6, 7] studied the application of composite structures for automobiles. However, the research was limited to doubly symmetric beams with simply supported boundary conditions. Free vibration of thin-walled beams with variable I-section by finite element method was studied by Wekezer [8, 9]. Only a few works have addressed the dynamic behaviour of composite thin-walled members. Bauld and Tzeng [10] extended Vlasov's thin-walled bar theory [11] to symmetric fiber-reinforced laminates to derive buckling equations of composite thin-walled beams. Song and Librescu [12] proposed an analytical model to predict free vibration behaviour of laminated composite thin-walled beams of open sections. They investigated natural frequency and mode shape with respect to the fiber orientation for composite box-section beams. Recently Lee and Kim [13] presented a general analytical model to predict buckling loads and mode shapes of thin-walled composites. In the present thesis, the analytical model developed by Lee and Kim [13] is taken and the dynamic behaviour of a thin-walled I-section composite beam is studied in detail. In the present study, the effect of laminated orthotropic I-Section beam has been analyzed. Two boundary conditions are considered: (i) Constraint simply supported boundary and (ii) clamped boundary condition. Further different composite materials have been chosen for the analysis to highlight the effect on the frequencies.

II. SPECIFICATION OF THE PROBLEM

The objective of the present work is to suggest a best available composite material for design, fabricate complete composite I-section beam

Length of the Beam l = 8m,
Width of top flange $b_1 = 0.1$m,
Width of bottom flange $b_2 = 0.1$m,
Width of web $b_3 = 0.20$m,
Thickness of top flange $t_1 = 0.01$m,
Thickness of top flange $t_2 = 0.01$m,
Thickness of web $t_3 = 0.01$m,
Cross section Area A = 0.0039 m^2

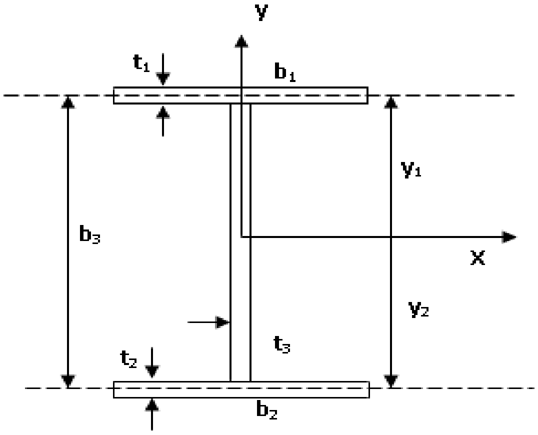


Figure 2: Geometry of a thin-walled composite I-beam.

III. FINITE ELEMENT ANALYSIS OF THIN-WALLED COMPOSITE I-BEAM

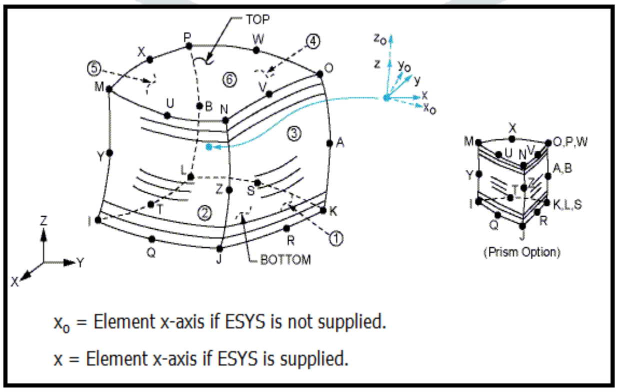
A thin-walled composite beam with I-section and length = 8 m is considered in order to investigate the effects of fiber orientation and boundary conditions on the natural frequencies and mode shapes.

Table 1. Material properties of different composites.

	E-Glass/Epoxy	Kevlar49/Epoxy	Carbon/Epoxy	Boron/Al	SiC/Carbide	Graphite/Epoxy
E_{12}	41	80	147	235	204	294
E_{23}	10.4	5.5	10.3	137	118	6.4
E_{13}	10.4	5.5	10.3	137	118	6.4
ν_{12}	0.28	0.34	0.27	0.3	0.27	0.23
ν_{23}	0.28	0.34	0.27	0.3	0.27	0.23
ν_{13}	0.28	0.34	0.27	0.3	0.27	0.23
G_{12}	4.3	2.2	7	47	41	4.9
G_{23}	3.5	1.8	3.7	28.2	24.6	2.94
G_{13}	4.3	2.2	7	47	41	4.9

3.1 Element used:

The element considered for the composite beam analysis is Solid 186, SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperplastic materials. SOLID186 Layered Structural Solid to model layered thick shells or solids.



x_o = Element x-axis if ESYS is not supplied.

x = Element x-axis if ESYS is supplied.

Figure 3: SOLID186 Layered Structural Solid Geometry

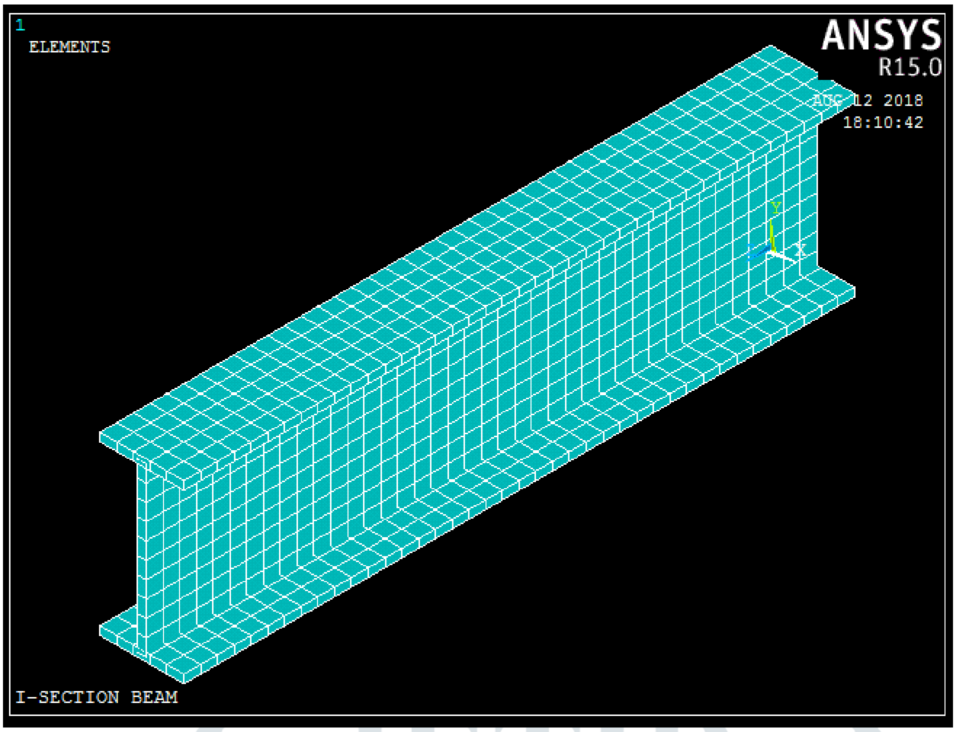


Figure 4: FE model of composite I-Section Beam

3.2 Modal analysis

Various materials are used such as E-Glass/Epoxy,Kevlar49/Epoxy, Carbon/Epoxy, Boron/AL, Sic/Carbide, Graphite/Epoxy, for I-Section beam are considered for analysis having same weight and same length L= 8m with different Boundary conditions like simply supported condition and different staking sequences like [30/-60/30/-60],[45/-45/45/-45],[0/90/90/0] with four layers. The four natural frequencies by the finite element analysis exactly correspond to the first flexural mode in the z-direction, first flexural mode in the y-direction, second flexural mode in the z-direction, and torsional mode, respectively.

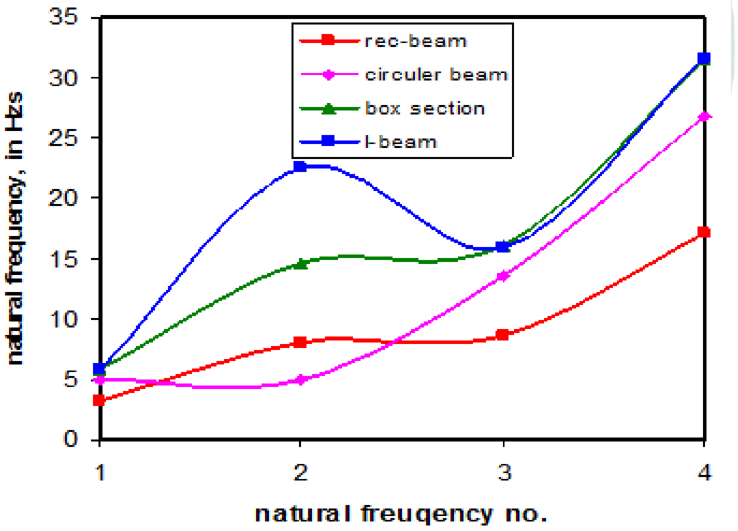


Figure 5: Natural frequencies of various thin walled beams.

When different beams are considered for same weight, it is clear that the first flexural mode in the y-direction (natural frequency number 2) for I-beam is found to be high and it is also noticed high for all modes for I-beam as shown in fig.5. So, the open section beams shows better performance over closed section beams for same weight.

IV. RESULTS AND DISCUSSION

FEA results of the I-Section beam with various materials under various boundary conditions and various staking sequences.

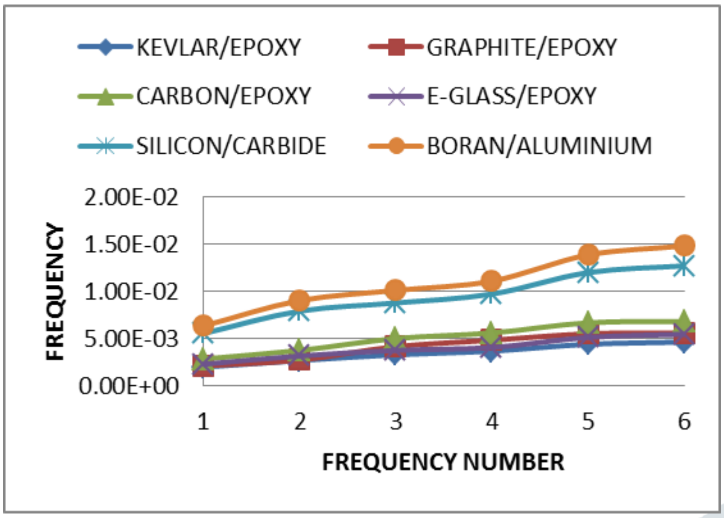


Figure 6: [30/-60/30/-60] clamped condition

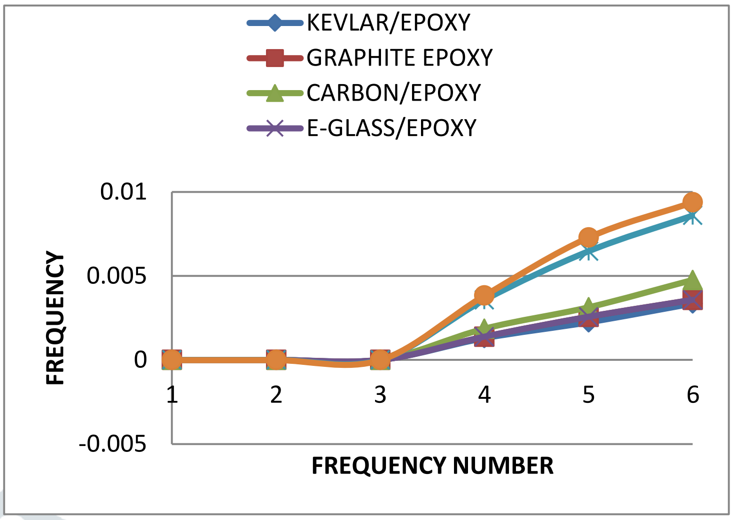


Figure 7: [30/-60/30/-60] simply supported condition

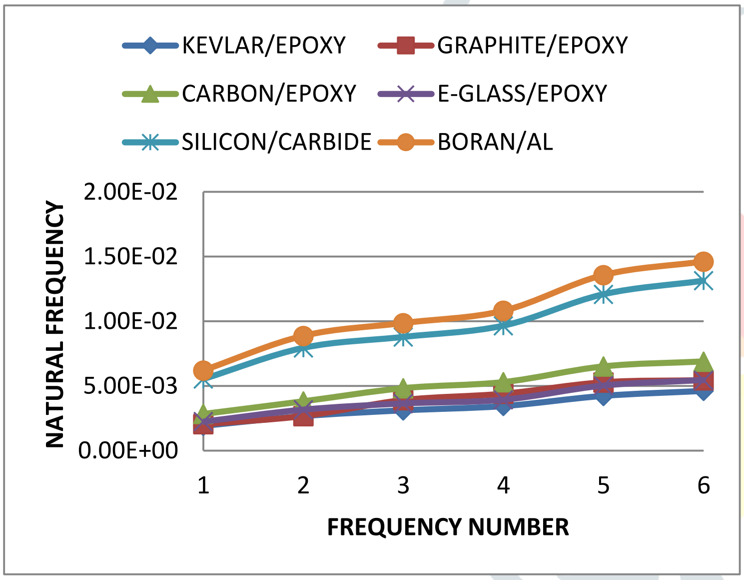


Figure 8: [45/-45/45/-45] clamped condition

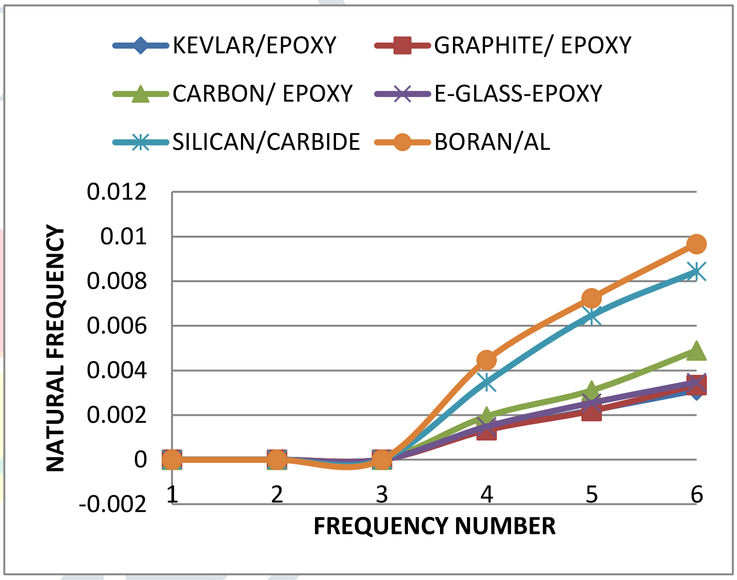


Figure 9: [45/-45/45/-45] simply supported condition

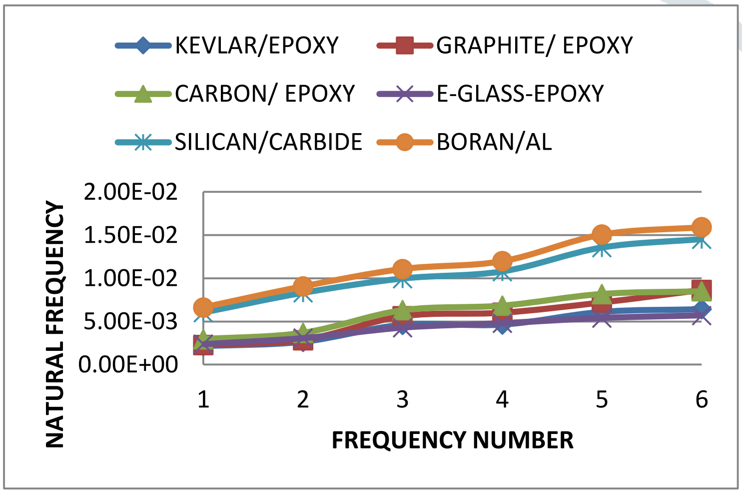


Figure 10: [0/90/90/0] Clamped condition

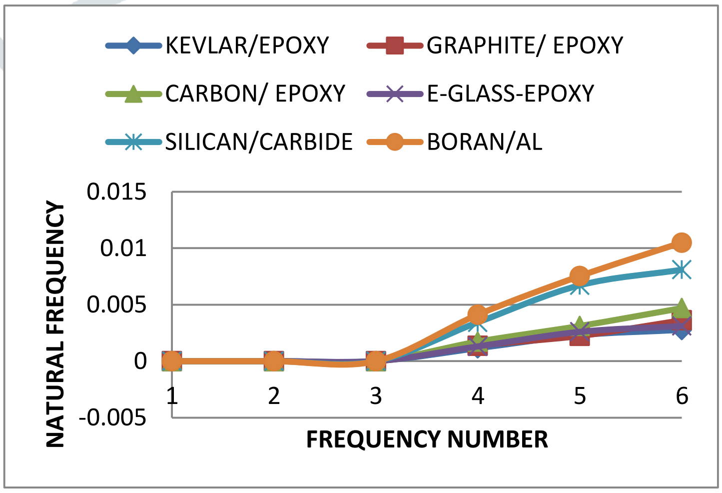


Figure 11: [0/90/90/0] simply supported condition

Fig.6 represents the natural frequencies of different composite materials with four layers with uniform thickness and the staking sequence of [30/-60/30/-60] with the clamped boundary condition. Among the materials Boron/AL shows high frequencies from one to six and least showing E-Glass/Epoxy. Fig.7 represents the natural frequencies of different composite materials with four layers with uniform thickness and the staking sequence of [30/-60/30/-60] with the simply supported boundary condition. Among the materials Boron/AL shows high frequencies from one to six and least showing E-Glass/Epoxy and

Graphite/Epoxy. Fig.8 represents the natural frequencies of different composite materials with four layers with uniform thickness and the staking sequence of [45/-45/45/-45] with the clamped boundary condition. Among the materials Boron/AL shows high frequencies from one to six and least showing Kevlar/Epoxy. Fig.9. represents the natural frequencies of different composite materials with four layers with uniform thickness and the staking sequence of [45/-45/45/-45] with the simply supported boundary condition. Among the materials Boron/AL shows high frequencies from one to six and least showing Kevlar/Epoxy. E-Glass/Epoxy and Graphite/Epoxy. Fig.10. represents the natural frequencies of different composite materials with four layers with uniform thickness and the staking sequence of [0/90/90/-0] with the clamped boundary condition. Among the materials Boron/AL shows high frequencies from one to six and least showing E-Glass/Epoxy. Fig.11. represents the natural frequencies of different composite materials with four layers with uniform thickness and the staking sequence of [0/90/90/0] with the simply supported boundary condition. Among the materials Boron/AL shows high frequencies from one to six and least showing Sic/Carbide.

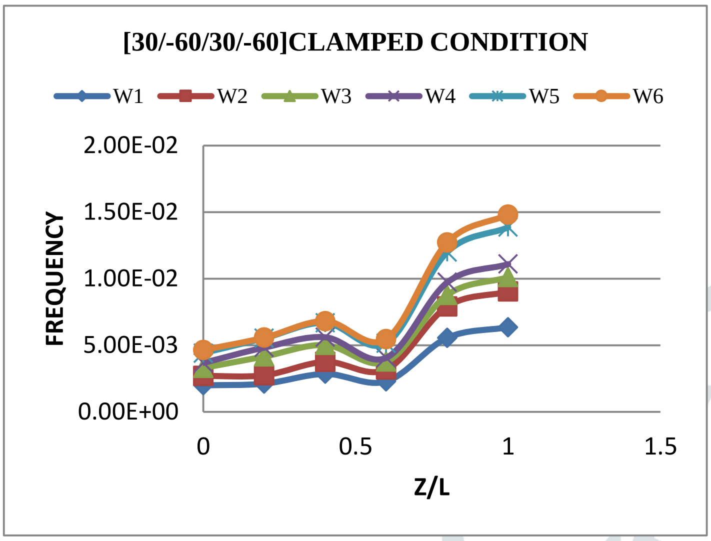


Figure 12: Mode shapes for composites

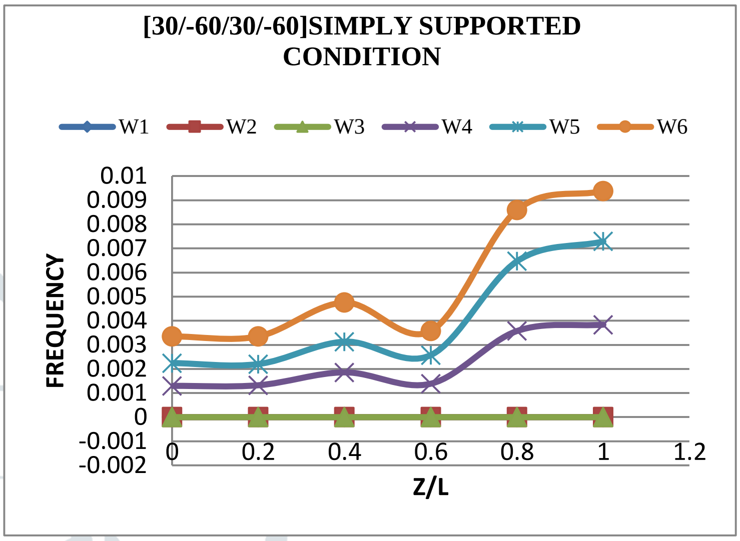


Figure 13: Mode shapes of the composites

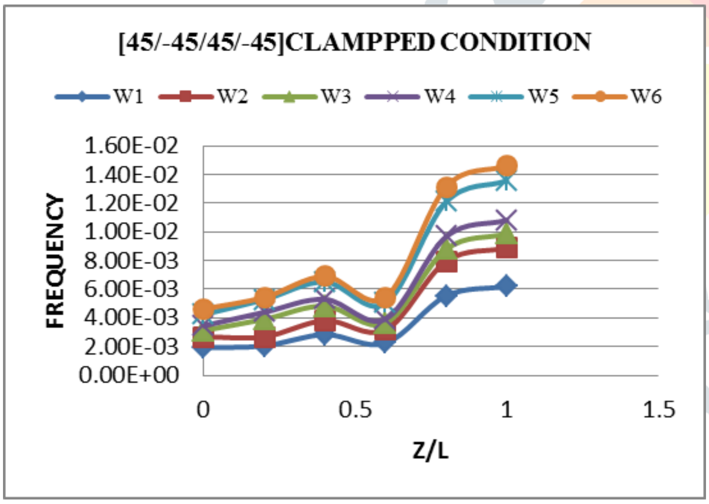


Figure 14: Mode shapes of the composites

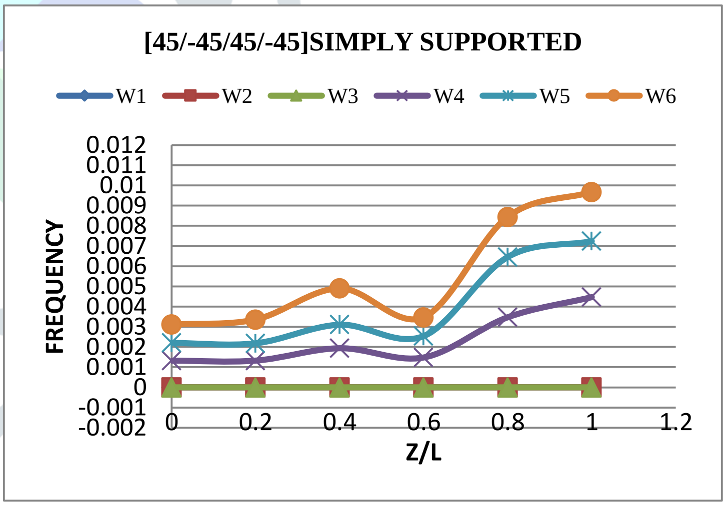


Figure 15: Mode shapes of the composites

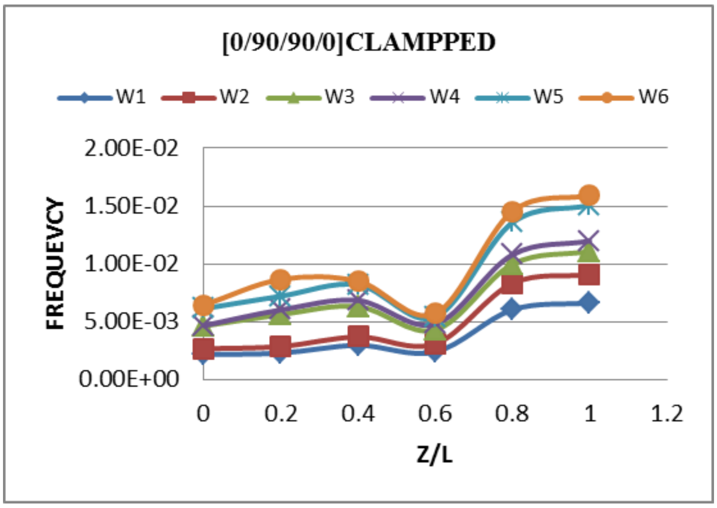


Figure 16: Mode shapes of the composites

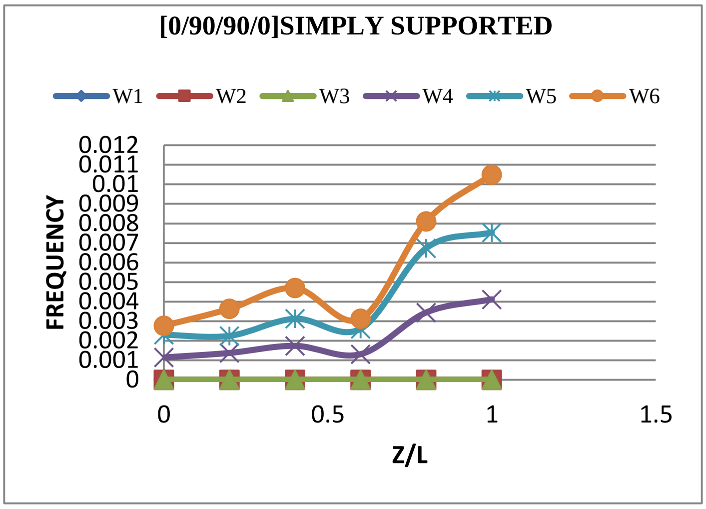


Figure 17: Mode shapes of the composites

Fig.12 to 17 represents frequency s Z/L plots, with different composite materials, different boundary conditions and different staking sequences. B. Raghu Kumar [14] represented that Boran aluminum shows good results when compared to other composite materials in his study.

Table 2. Comparision results of deflection and stress.

S/NO	Material	Max deflection(mm)	Max stress(Mpa)	Weight(Kg)
1	Steel	77	425.17	26
2	Boran Aluminum	35.97	345.78	2.52

V. CONCLUSION

Composite I-Section beam with the length of 80M constant cross section with different materials has been developed. The I-section beam is analyzed in ANSYS software with different composite materials along with the steel. A comparative study has been made between different composite materials and with the steel in respect of weight, deflection natural frequencies. It can be observed that in case of finding natural frequencies the staking sequence [0/90/90/0] is giving high frequencies when compared to remaining staking sequences. and we can observe simply supported condition only giving high frequencies. And from the first two modes there will not be any change in any material in simply supported condition. From third frequency there is a drastic change in all materials. But Boron Aluminum shows the results which will gives the near values to steel. Boron Aluminum is the best suitable material for replacing the steel in manufacturing of I-Section beam. The savings in the weight is 90.3%. It will shows the high natural frequency among all the other materials in this study.

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