Vibration Analysis of Laminate Beams and Study of Relation between Core Thickness and Natural Frequency

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Abstract: This paper examines the study of implementation of laminate structure in place of conventional Steel beam. To validate the idea, laminate beams is studied as variety of engineering components can be approximated as laminated beams. In laminate beam, sandwich core combinations of aluminium as face material and PVC solid as core material for different thickness has been studied. The relation of core thickness to Natural Frequency and Bending Stiffness has been established. Improvement in natural frequency is obtained with very little weight increase than the conventional metal beams.

Index terms: Laminate Beams, Natural Frequency, NVH, Bending Stiffness.

I. INTRODUCTION

Automotive industry today is growing vertically and horizontally as the demand for personal vehicle has been rising continuously over the past years. Automotive companies spend huge amount of resources in Research and Development of vehicles. From last decade, In Research and Developments main priority is given to weight reduction as reduction of weight has many advantages. In the car industry today, one of the things that the highest focus is on is the fuel consumption of the car and the emissions from the car. This is because the environmental rules becomes tougher and tougher, and with lower fuel consumption and with lower fuel consumption and emission the cars damage the environment less. Automotive weight reduction with laminate structure makes an important contribution to this, especially because it can be achieved ecologically and economically. This makes it a practicable solution even for small and mid-size vehicles where cost pressure is high – i.e. the majority of all cars.

There are many ways to lower emissions and fuel consumption, one is to lower the total weight of the car, by lowering the mass of the different parts of the car leads to a lower total weight. Especially in the front of the vehicle is very important in goal to making cars. By introducing laminate material to the hood, there are possibilities to make a hood with the same properties but with a lower mass.

Lighter cars are quicker and the handling is much better. Not only are lightweight vehicles energy efficient, but they also enhance performance. Lightweight materials are essential for boosting the fuel economy of modern cars while maintaining their safety and performance. Because it takes less energy to accelerate a lighter car than a heavier one. Automotive weight reduction with laminate. structure makes an important contribution to this, especially because it can be achieved ecologically and economically. This makes it a practicable solution even for small and mid-size vehicles where cost pressure is high – i.e. the majority of all cars. When automakers reduce the weight of a vehicle by 10%, they boost the fuel economy of that vehicle by 6 to 8%

When automakers reduce the weight of a vehicle by 10%, they boost the fuel economy of that vehicle by 6 to 8%. With less weight for the suspension and tyres to control, overall handling and cornering speed is improved. Adjusting the weight distribution by removing weight from the front or rear of the car can affect how much it over or under steers, and removing weight from higher up in the car lowers the centre of gravity – another great thing for handling. Reliability is also high because lower weight literally puts less stress on everything.

II. STUDY OF LAMINATE STRUCTURE

A sandwich-structured material is a special class of materials that is fabricated by bonding two thin but stiff skins to a lightweight but a relatively thick core. The core can vary in different structures and material depending on which properties that are needed. The different structures that can be used as a core structures is polymer foams, metal foams, balsa wood, and various honeycomb structures.[6]

1) Core

The Polymer solid core has been chosen. The Polymer solid core types gives the sandwich good energy absorption, which was the material property needed to get a good pedestrian head impact value in the automotive parts.

They also give the beams a good strength to weight ratio that is a material property needed to fulfill the demand about overall stiffness. The bending stiffness of the sandwich is depends on the thickness of the core, and with thicker core an increase in stiffness is achieved for very little extra weight.

2) Face

The best face material should be Aluminum, the explanation behind that decision is :First, the material property that the aluminum material can be plastically deformed. That is a good property to have in a high speed crash when the hood needs to bend.Second, aluminum is also good considering the head impact, because of lower stiffness than CFRP, gives the hood a better damping effect instead of a hard hood with low flex. The possibility of plastic deformation when the head hits the hood, there is a low risk that it breaks, and is more likely to get a dent. Compared to the carbon fiber where it is a risk of sharp edges, and risk of damage on the person that the car hits.

3) Adhesives

The core is bonded to the skins with an adhesive. Epoxy adhesives is used as it has a better heat and chemical resistance than other common adhesives. Epoxy adhesives can be developed to suit almost any application.

The material details are as follows.

Material	Young' Modulus	Density	Poisson's Ratio
Steel	210GPa	7850Kg/m3	0.3
Aluminium	69GPa	2700Kg/m3	0.35
PVC Solid	4.14GPa	400kg/m3	0.4
	3.81GPa	1200/kgm3	0.41

Table 1 : Materials properties used in simulation

III. CALCULATION ON BEAMS

A Beam of length 450mm and width 20mm is taken for simulation and theoretical calculations. Thickness is varied as per the different configuration of beams. Element size used is 10mm.
Shell Elements is used for Aluminum and Hexa solid element for PVC solid and Epoxy adhesives.
Below are the laminate beam exploded view.

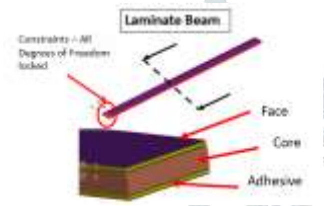


Figure 1: Laminate Beam of Alumnium and PVC solid core

Natural Frequency and Bending Stiffness

In the development phase, it is critical to know the natural frequencies of the structure. If a natural frequency of the structure is close to an excitation frequency of other system, then extreme vibration can occur. This condition is called resonance and to avoid resonance, the natural frequencies of the structure must be altered by making suitable adjustments in the design. Therefore it is very important in finding the dynamic response of the elastic structure as it's subjected to different working environment
The objective of calculating natural frequencies with different core thickness is to establish a relation a relation between natural frequency and the thickness of the core. One end of the beam is fixed with other end open, the natural frequency has been calculated for all different beams.

A closed form of the circular natural frequency ω_{nf}, from equation of motion and boundary conditions can be written as,

$$\omega_{nf} = \alpha_n^2 \sqrt{\frac{EI}{mL^4}}$$

The natural frequency is related with the circular natural frequency as

$$f_{nf} = \frac{\omega_{nf}}{2\pi} \text{Hz}$$

where,
ω – Circular natural frequency
Fn – Natural Frequency
E – Young's Modulus
I – Moment of Inertia
M – Mass of the beam
α – constant 1.875 . For first Mode

The bending stiffness (K) is the resistance of a member against bending deformation. It is a function of the Young's modulus E, the area moment of inertia I of the beam cross-section about the axis of interest, length of the beam and beam boundary condition.

Bending Stiffness = (Ef * w * t3)/6) + (Ef *w * t * d2)/2) + (Ec * w * c3)/12)

where,
Ef – Young's Modulus of Face material
Ec – Young's Modulus of Core material
w – Width of Beam
t – Thickness of Face
c – Thickness of core
d – c + t

The natural frequency for Steel and Aluminium Beam with thickness 3.0mm are as follows.

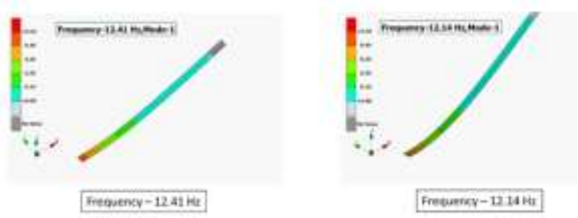


Figure 2 Modal Analysis of Steel Beam

Now the laminate beam with aluminum as a face material and PVC Solid as core material is simulated for different core thickness and its natural frequencies has been founded.

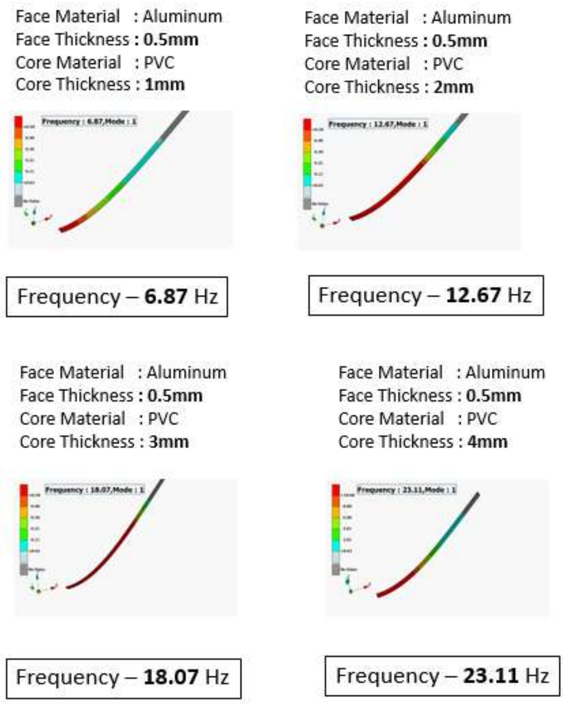


Figure 3 Modal Analysis of Laminate Beans with different Core thickness

IV. RELATION OF CORE THICKNESS WITH NATURAL FREQUENCY AND BENDING STIFFNESS

The Natural Frequency and Bending Stiffness of Conventional Beam are as follows:
Thickness considered for this beams is 3.0mm

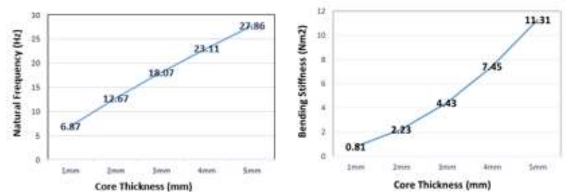
Material	Thickness (mm)	Theoretical Natural Frequency (Hz)	FEA Natural Frequency (Hz)	Bending Stiffness	Mass
Steel	3.0	12.37	12.41	9.45	212
Aluminium	3.0	12.09	12.14	3.1	73

Table 2: Conventional Metal Beam Frequency Comparison

Material		Thickness		FEA Natural Frequency (Hz)	Bending Stiffness (Nm2)	Mass (g)
Face	Core	Face	Core			
Al	PVC	0.5	1	6.87	0.81	28.0
Al	PVC	0.5	2	12.67	2.23	31.5
Al	PVC	0.5	3	18.07	4.43	35.1
Al	PVC	0.5	4	23.11	7.45	38.7
Al	PVC	0.5	5	27.86	11.31	42.3

Table 3 : Laminate Beam Frequency Comparison

In the above tables it is found that increasing the core thickness is increasing the Natural frequency and Bending Stiffness of the beam with a very little increase in weight. In the below graphs we have compared the effect of increasing core thickness with Natural Frequency and Bending Stiffness.



Graph 1 Core Thickness vs Natural Frequency and Bending Stiffness

CONCLUSION

Lighter structure is possible with the use of aluminium as a face material and PVC Solid as a core material. . Use of Laminate structure in beam helps in reducing weight and can be used in various automotive applications where weight reduction is required. In Laminate Structure, Aluminium as a face material helps in deforming elastically & the stiffness and elongation property of PVC Foam helps in good energy absorption.

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