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Fracture Analysis of Delaminated Composite Beams Using Analytical and Numerical Methods

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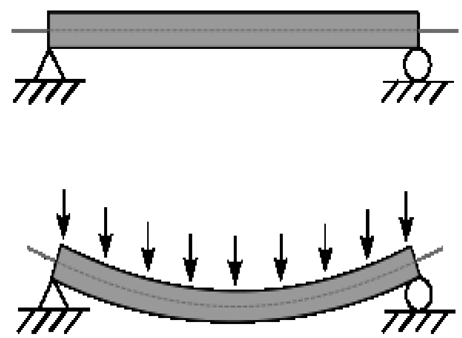
ABSTRACT

In this thesis, the effects of delamination length on the deformations, stresses, stress intensity factors and frequencies for composite beams are analyzed using Ansys software. The composite materials considered are E Glass Fiber, S2 Glass and Aramid Fiber. Static, Fracture and Frequency analysis are done on the composite beam by varying number of layers 3, 5 & 7. By this the effect of delamination is determined. Numerical calculations are also done to compare with that of analytical results.

INTRODUCTION

A beam is a structural element that is capable of withstanding load primarily by resisting bending. The bending force induced into the material of the beam as a result of the external loads, own weight, span and external reactions to these loads is called a bending moment.

Beams are traditionally descriptions of building or civil engineering structural elements, but smaller structures such as truck or automobile frames, machine frames, and other mechanical or structural systems contain beam structures that are designed and analyzed in a similar fashion.



Statically determinate beam, bending (sagging) under an evenly distributed load

Overview

Historically beams were squared timbers but are also metal, stone, or combinations of wood and metal such as a flitch beam. Beams generally carry vertical gravitational forces but can also be used to carry horizontal loads (e.g., loads due to an earthquake or wind or in tension to resist rafter thrust as a tie beam or (usually) compression as a collar beam). The loads carried by a beam are transferred to columns, walls, or girders, which then transfer the force to adjacent structural compression members. In light frame construction joists may rest on beams.

In carpentry a beam is called a plate as in a sill plate or wall plate, beam as in a summer beam or dragon beam.

Types of beams

In engineering, beams are of several types:

Simply supported - a beam supported on the ends which are free to rotate and have no moment resistance.
Fixed - a beam supported on both ends and restrained from rotation.
Over hanging - a simple beam extending beyond its support on one end.
Double overhanging - a simple beam with both ends extending beyond its supports on both ends.
Continuous - a beam extending over more than two supports.
Cantilever - a projecting beam fixed only at one end.
Trussed - a beam strengthened by adding a cable or rod to form a truss.

Structural characteristics

Moment of inertia

The moment of inertia of an object about a given axis describes how difficult it is to change its angular motion about that axis. Therefore, it encompasses not just how much mass the object has overall, but how far each bit of mass is from the axis. The farther out the object's mass is, the more rotational inertia the object has, and the more force is required to change its rotation rate.
Diagram of stiffness of a simple square beam (A) and universal beam (B). The universal beam flange sections are three times further apart than the solid beam's upper and lower halves. The second moment of inertia of the universal beam is nine times that of the square beam of equal cross section (universal beam web ignored for simplification)

Stress in beams

Internally, beams experience compressive, tensile and shear stresses as a result of the loads applied to them. Typically, under gravity loads, the original length of the beam is slightly reduced to enclose a smaller radius arc at the top of the beam, resulting in compression, while the same original beam length at the bottom of the beam is slightly stretched to enclose a larger radius arc, and so is under tension. The same original length of the middle of the beam, generally halfway between the top and bottom, is the same as the radial arc of bending, and so it is under neither compression nor tension, and defines the neutral axis (dotted line in the beam figure). Above the supports, the beam is exposed to shear stress. There are some reinforced concrete beams in which the concrete is entirely in compression with tensile forces taken by steel tendons. These beams are known as prestressed concrete beams, and are fabricated to produce a compression more than the expected tension under loading conditions. High strength steel tendons are stretched while the beam is cast over them. Then, when the concrete has cured, the tendons are slowly released and the beam is immediately under eccentric axial loads. This eccentric loading creates an internal moment, and, in turn, increases the moment carrying capacity of the beam. They are commonly used on highway bridges.
The primary tool for structural analysis of beams is the Euler–Bernoulli beam equation. Europe has superseded Euler-Bernoulli equations with the Perry Robertson formula. Other mathematical methods for determining the deflection of beams include "method of virtual work" and the "slope deflection method". Engineers are interested in determining deflections because the beam may be in direct contact with a brittle material such as glass. Beam deflections are also minimized for aesthetic reasons. A visibly sagging beam, even if structurally safe, is unsightly and to be avoided. A stiffer beam (high modulus of elasticity and high second moment of area) produces less deflection.
Mathematical methods for determining the beam forces (internal forces of the beam and the forces that are imposed on the beam support) include the "moment distribution method", the force or flexibility method and the direct stiffness method.

LITERATURE SURVEY

PAPER 1 - A Dynamic Stiffness Element for Free Vibration Analysis of Delaminated Layered Beams by Nicholas H. Erdelyi and Seyed M. Hashemi

A dynamic stiffness element for flexural vibration analysis of delaminated multilayer beams is developed and subsequently used to investigate the natural frequencies and modes of two-layer beam configurations. Using the Euler-Bernoulli bending beam theory, the governing differential equations are exploited and representative, frequency-dependent, field variables are chosen based on the closed form solution to these equations. The boundary conditions are then imposed to formulate the dynamic stiffness matrix (DSM), which relates harmonically varying loads to harmonically varying displacements at the beam ends. The bending vibration of an illustrative example problem, characterized by delamination zone of variable length, is investigated. Two computer codes, based on the conventional Finite Element Method (FEM) and the analytical solutions reported in the literature, are also developed and used for comparison. The intact and defective beam natural frequencies and modes obtained from the proposed DSM method are presented along with the FEM and analytical results and those available in the literature.

PAPER 2 - Frequency response analysis of a delaminated smart composite plate by Bin Huang, Heung Soo Kim

A frequency analysis of smart composite plate with delamination at ply interface was investigated in this article. The modeling was based on an electro-mechanical coupled improved layerwise theory, with implementing finite element method. Four-node plate elements with Lagrange and Hermite cubic interpolation functions were used for in-plane structural unknowns, electric unknowns, and out-of-plane structural unknowns. The general modal reduction method was applied to solve the second-order differential equation. Numerical results showed significant shift of natural frequencies in the frequency response of tip displacement and three sensor outputs due to the presence of delamination. It is found that the delamination locations also influence the natural frequencies of smart composite structure. Thus, the proposed methodology could be a useful tool to develop system identification and structural health monitoring techniques of smart composite structure.

PAPER 3 - Vibration Analysis of Delaminated Composite Laminates in Prebuckled States Based on a New Constrained Model by Hsin-Piao Chen, John J. Tracy, RamonNonato

An analytical model of free vibration of a delaminated composite laminate in prebuckled states has been developed. The formulation is based on a new constrained model which includes both effects of the compressive force and bending-extension coupling. These two effects on the natural frequency of delaminated plates have not been studied by such a model before. It is found that the compressive force, laminate lay-up, delamination length, and delamination locations in the thickness-wise and spanwise directions are significant factors to determine the vibration characteristics. Experiments have been conducted to validate this analytical model. Good agreements between the analytical results and test data have been obtained.

PAPER 4 - Analytical solution for the dynamic analysis of a delaminated composite beam traversed by a moving constant force by Mohammad H Kargarnovin, Mohammad T Ahmadian, Ramazan-Ali Jafari-Talookolaei

A closed form solution is presented in this paper to study the dynamics of a composite beam with a single delamination under the action of a moving constant force. The delaminated beam is divided into four interconnected beams using the delamination limits as their boundaries. Governing motion equations are derived in which the differential stretching and the bending-extension coupling are considered. The method

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of modal analysis is adopted to derive analytically the dynamic response of each beam. The obtained results for the free vibrations of delaminated beam are verified against reported similar results in the literature. Moreover, the maximum dynamic response of such a beam is compared with a healthy beam. The effects of different parameters such as the force velocity, different ply configuration and the size, depth and spanwise location of the single delamination on the dynamic response of the beam are studied. It is noticed that the presence of delamination has significant influence on the dynamic response of the beam.

PAPER 5 - Free vibration analysis of delaminated composite beams by Jaehong Lee

Free vibration analysis of a laminated beam with delaminations is presented using a layerwise theory. Equations of motion are derived from the Hamilton's principle, and a finite element method is developed to formulate the problem. Numerical results are obtained and compared with those of other theories addressing the effects of the lamination angle, location, size and number of delamination on vibration frequencies of delaminated beams. It is found that a layerwise approach is adequate for vibration analysis of delaminated composites.

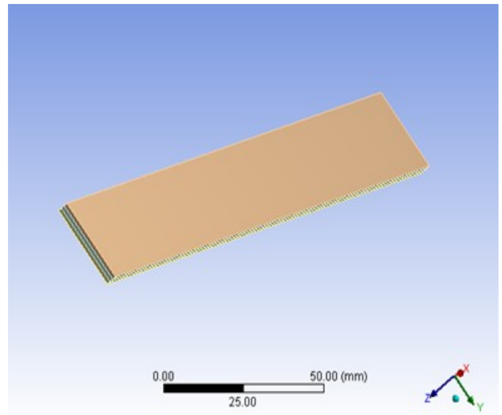

Fig: Imported model

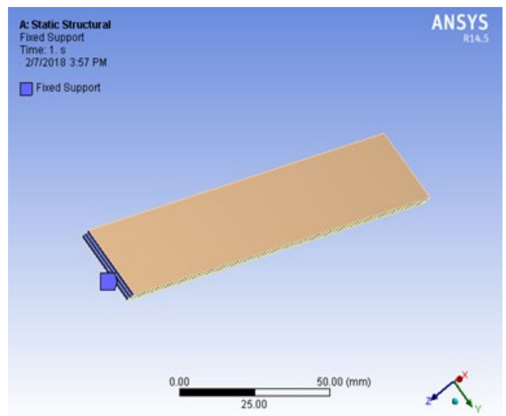

Fig: Fixed support

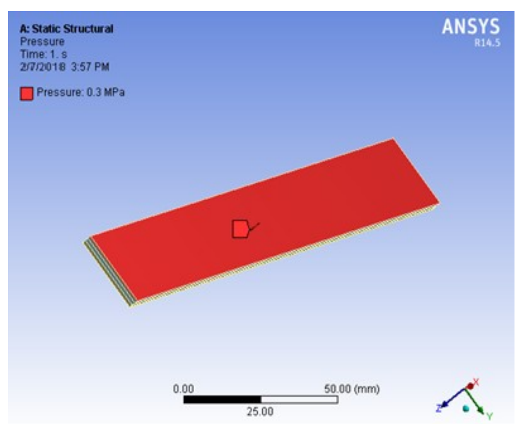

Fig: Pressure

ANALYSIS

MATERIAL - E-GLASS EPOXY

RESULTS TABLE

Static analysis

Material	No. layers	Deformation (mm)	Stress (MPa)	Strain

E-Glass epoxy	**3**	91.946	2083.9	0.028864
	5	20.358	758.73	0.010508
	7	7.7539	87.71	0.012027
Aramid fiber	**3**	612.79	2160.3	0.19682
	5	137.16	1744.2	0.15858
	7	47.317	383.74	0.035301
S-2 glass	**3**	130.16	2496	0.049443
	5	26.114	761.52	0.013893
	7	9.7985	386.2	0.0070219

Fracture analysis

Material	No. layers	JINT	SIFS-K1	SIFS-K2	SIFS-K3
e-glass epoxy	**3**	16.334	1112.4	4.9488	2.3517
	5	0.44308	156.39	0.68813	1.4584
	7	0.11775	54.583	0.34487	0.71329
Aramid fiber	**3**	81.322	900.45	4.7799	3.3335
	5	5.1458	146.95	0.98712	1.8224
	7	0.16855	53.844	0.18053	0.38261
S-2 glass	**3**	21.266	1109.1	1.0614	2.8774
	5	0.28459	155.74	0.53741	0.86462
	7	0.084047	55.124	0.22473	0.53727

Modal analysis

Material		E-Glass epoxy			Aramid fiber			S-2 Glass		
No. layers		3	5	7	3	5	7	3	5	7
Mode 1	Frequency (HZ)	115.96	193.93	266.45	90.667	127.28	141.12	233.11	268.65	330.42
	Deformation (mm)	179.9	140.97	120.3	155.09	222.46	227.02	509.4	189.53	166.18
Mode 2	Frequency (HZ)	312.4	520.02	716.49	459.61	249.35	383.26	545.48	632.56	888.69
	Deformation (mm)	162.8	132.74	117.62	278.83	244.3	146.79	416.45	179.06	157.49
Mode 3	Frequency (HZ)	610.56	859.21	856.23	507.63	459.86	448.43	1085	1037.7	1051.4
	Deformation (mm)	197.82	137.86	115.59	437.14	191.26	153.8	296.44	188.59	162.45

CONCLUSION

In this thesis, the effects of delamination length on the deformations, stresses, stress intensity factors and frequencies for composite beams are analyzed using Ansys software. The composite materials considered are E Glass Fiber, S2 Glass and Aramid Fiber. Static, Fracture, Frequency and Random vibration analysis are done on the composite beam by varying number of layers 3, 5

& 7. By this the effect of delamination is determined. The parameters are considered as per Taguchi technique.

By observing analysis results, the deformation and stress values are decreasing by increasing the number of layers. The values are less for E – Glass with 0.8mm delamination length and with 7 layers. Stress intensity factors are less for Aramid Fiber with 0.8mm delamination length and with 7 layers and J – Integral are less for S2 – Glass with 0.5mm delamination length and with 7 layers. Frequencies are less for Aramid Fiber with 0.5mm delamination length and with 3 layers. By decreasing the frequencies, the vibrations will decrease.

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[4] Analytical solution for the dynamic analysis of a delaminated composite beam traversed by a moving constant force by Mohammad H Kargarnovin, Mohammad T Ahmadian, Ramazan-Ali Jafari-Talookolaei

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